

FERMENTATION CHARACTERISTICS AND NUTRITIONAL  
VALUE OF *OPUNTIA FICUS-INDICA* VAR. *FUSICAULIS*  
CLADODE SILAGE

by

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## Declaration

I declare that this thesis submitted by me to the University of the Free State for the degree **MAGISTER SCIENTIAE AGRICULTURAE (M.Sc. Agric.)** Animal science is my own independent work and has not previously been submitted by me for a degree at any other University / Faculty. I further cede copyright of this thesis in favour of the University of the Free State.

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Hugh Mciteka

## TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	2
DECLARATION	3
ABBREVIATIONS	7
<b>Chapter 1</b>	
<b>GENERAL INTRODUCTION</b>	8
<b>Chapter 2</b>	
<b>LITERATURE REVIEW</b>	11
2.1 Introduction	11
2.2 Prickly pear in South Africa	11
2.3 Prickly pear in other countries	12
2.4 Prickly pear cladodes as a drought resistant fodder	13
2.4.1 Drought resistant properties	14
2.5 Feeding value of spineless cactus ( <i>Opuntia ficus indica</i> )	15
2.6 Utilization of spineless cactus	16
2.6.1 Grazing	16
2.6.2 Cut and carry	17
2.6.3 Dried pads	17
2.6.4 Supplementation of spineless cactus	17
2.6.5 Silage	18
2.6.5.1 Basic principles of making silage	18
2.6.5.2 Factors affecting silage quality	21
2.6.5.3 Factors affecting silage utilization	29
2.6.5.4 Silage quality	30
<b>Chapter 3</b>	
<b>CHEMICAL COMPOSITION OF DIFFERENT <i>OPUNTIA FICUS-INDICA</i> CLADODES VARIETIES</b>	
3.1 Introduction	33
3.2 Materials and Methods	33
3.2.1 Sampling	33
3.2.2 Chemical analysis	34
3.2.3 Statistical analysis	34
3.3 Results and Discussion	34
3.3.1 Dry matter	36
3.3.2 Ash	36
3.3.3 Organic matter	37

3.3.4	Crude protein	37
3.3.5	Acid Detergent Fibre	38
3.3.6	Neutral Detergent Fibre	39
3.3.7	Cellulose	39
3.3.8	Hemicellulose	40
3.3.9	Lignin	40
3.3.10	Non Fibre Carbohydrates	41
3.3.11	Ether extracts	42
3.3.12	Minerals	42
3.3.12.1	Phosphorus	42
3.3.12.2	Potassium	43
3.3.12.3	Calcium	43
3.3.12.4	Magnesium	44
3.3.12.5	Sodium	44
3.4	Conclusions	45

## Chapter 4

### **THE FERMENTATION CHARACTERISTICS OF *OPUNTIA FICUS-INDICA* var. *FUSICAULUS***

4.1	Introduction	46
4.2	Materials and Methods	47
4.2.1	Ensiling	47
4.2.2	Sampling procedure	50
4.2.3	Chemical analysis	51
4.3	Statistical analysis	51
4.4	Results and Discussion	51
4.4.1	Dry matter	51
4.4.2	Chemical composition	53
4.4.2.1	Acid and Neutral detergent fibre	55
4.4.2.2	Crude protein	56
4.4.2.3	Ether extracts	57
4.4.3	Volatile fatty acids	57
4.4.3.1	Acetic acid	58
4.4.3.2	Propionic acid	60
4.4.3.3	Butyric acid	61
4.4.4	Lactic acid	62
4.4.5	Water soluble carbohydrates	63
4.4.6	pH	64
4.4.7	<i>In vitro</i> dry matter digestibility	65
4.4.8	Gross energy	66
4.5	Conclusions	67

## **Chapter 5**

### **THE DIGESTIBILITY OF *OPUNTIA FICUS - INDICA* var. *FUSICAULUS***

#### **CLADODE SILAGE**

5.1	Introduction	69
5.2	Materials and Methods	70
5.2.1	Silage	70
5.2.2	Animals	71
5.3	Sampling procedure	72
5.3.1	Analysis	72
5.3.2	Statistical analysis	72
5.4	Results and Discussion	72
5.4.1	Digestibility study	72
5.4.1.1	Chemical composition	72
5.4.1.2	Dry matter intake	73
5.4.1.3	Digestibility coefficient	74
5.4.1.3.(a)	Dry matter	74
5.4.1.3.(b)	Organic matter	75
5.4.1.3.(c)	Acid and Neutral detergent fibre	76
5.4.1.3.(d)	Crude protein	77
5.4.1.3.(e)	Ether extract	77
5.4.1.4	Metabolizable energy	78
5.4.1.5	Intake study	79
5.4.1.5.(a)	Dry matter intake	79
5.4.1.5.(b)	Metabolizable energy intake	80
5.4.2.	Live-weight	81
5.5	Conclusions	82

## **Chapter 6**

<b>General conclusion</b>	83
<b>Abstract/Opsomming</b>	85
<b>REFERENCES</b>	89

## ABBREVIATIONS

AA	Acetic acid
ADF	Acid detergent fibre
BA	Butyric acid
Ca	Calcium
CAM	Crassulacean acid metabolism
CF	Crude fibre
CP	Crude protein
CV	Coefficient of variation
DM	Dry matter
DMI	Dry matter intake
DE	Digestible energy
EE	Ether extracts
GE	Gross energy
IVDMD	<i>In vitro</i> dry matter digestibility
K	Potassium
LA	Lactic acid
LAB	Lactic acid bacteria
Mg	Magnesium
ME	Metabolisable energy
MEI	Metabolisable energy intake
Mol	Molasses
NFC	Non fibre carbohydrates
N	Nitrogen
Na	Sodium
OM	Organic matter
P	Phosphorus
PA	Propionic acid
S	Sulfur
TDN	Total digestible nutrients
TVFA	Total volatile fatty acids
VFA	Volatile fatty acids
WSC	Water-soluble carbohydrates

## CHAPTER 1

### GENERAL INTRODUCTION

The search for appropriate plant species able to grow and to produce in arid areas was of a permanent concern of most people living in harsh environments. Drought is a natural and normal attribute of the arid lands and arid and semi-arid climates. The South African stock industries regularly suffer exceptionally large losses as a result of a scarcity of food during droughts. There is thus a shortage of low cost fodder, especially during drought. Therefore livestock farmers need to be better prepared to overcome drought conditions. One way to lessen the devastating effect of droughts is to establish drought-tolerant fodder crops in arid and semi-arid areas.

Prickly pear (*Opuntia*) and other cactus plants possess the remarkable quality of being able to take up and store water within a reasonably short time. For long periods these plants are then able to survive with very little rain. This quality of theirs makes them particularly useful, since periodic droughts are a phenomenon in many countries, particularly Southern African countries. Agricultural drought may be defined as a deficiency of rainfall in respect to the median or to the mean that seriously impairs agricultural production for a period of several months to several years, extending over a large geographical area (WMO,1975).

*Opuntias* (Cactus) are now part of the natural landscape and the agricultural systems of many regions of the world. Some species are even naturalized weeds in countries such as South Africa and Australia where the environmental conditions are particularly favourable. In many different countries the *Opuntias* and their products serve various purposes (as food, forage, energy, medicine, cosmetic, agronomic and others). It is indeed difficult to find more widespread and better exploited plant, particularly in the subsistence economy of arid and semi-arid zones, where farmers due to the lack of natural and productive resources, must look to those few species that can profitably survive and produce. Thus *Opuntias* have become an endless source of products and functions, initially as a wild plant and, later, as a crop for both a subsistence and a market-oriented agriculture (Barbera, 1995).



This is supported by the daily pattern of carbon dioxide (CO<sub>2</sub>) uptake and water loss, primarily at night when plants open their stomates. The carbon dioxide taken up is incorporated into various products of photosynthesis which takes place only in light. The fact is that the opening of the stomata at night when temperatures are lower and humidity is higher, resulted in a lower water loss (Noble, 1995).

Thus *Opuntia* plants attributes makes it an ideal “drought insurance” as it is adapted to withstand severe drought conditions and still produce fodder at a low cost. The cactus pear can also be used in agri-forestry systems with legumes and annual crops. Cactus pear can play a stabilizing role in agriculture as it can prevent stock losses during droughts, save natural grazing from over-utilization, increase farm income and alleviate poverty in rural areas (Potgieter, 1993). Rodriguez (1997) mentioned that traditionally, prickly pear cactus has been used as fruit, vegetable and forage.

Spineless cactus pears are valued by many farmers because of their drought resistance, high biomass yield, palatability and adaptability to a range of soils and climatic regions (Zeeman & Terblanche, 1979; Ben Salem *et al.*, 1996; Batista *et al.*, 2003). The voluntary dry mater (DM) intake by sheep of fresh spineless cactus pears is less than their maintenance requirements and the animals will loose body mass. The voluntary intake of dried and ground spineless cactus cladodes, with a much lower water content than other physical forms of spineless cactus pears, was markedly higher and consequently the loss in body mass was also much less (Jacobs, 1977).

Another possible problem experienced when cactus pear pads are fed in a fresh form is a laxative effect. This effect is not a disease symptom and has no detrimental effect on animals, but it has the disadvantage that food passes through the digestive tract faster, and digestibility is reduced. Where access to grazing veld is not possible, a supplement of any roughage or the adding of 3% feed lime to the ration will counteract the laxative effect (De Kock, 1998). It appears that hay, as a supplement, retards this laxative effect to a certain extent. This is another reason why lucerne hay is regarded as an exceptionally suitable supplement to spineless cactus in any form (De Kock, 1980).

Fruit production from spineless cactus for export is already an established and integral part of some farming enterprises in the Limpopo province. The expansion of this farming practice to other provinces in South Africa currently enjoys high priority in research. Besides the income from fruit production it has tremendous potential as regards job creation and small-scale farming. Fruit production necessitates the yearly pruning of the plant to get rid of diseases infected parts and to facilitate the harvesting of fruits. This available fresh plant material is mostly used as feed for sheep and beef cattle.

The cactus material could however be used more efficiently and strategically if it is preserved and stored as silage. A low sugar and high moisture content (90%) of cactus could probably hamper the effective fermentation and preservation of the plant material as silage. Ensiling of cactus plant material with lower moisture content could probably influence fermentation and dry matter intake of animals beneficial. The influence of ensiling of cactus plant material on the laxative effect and consequently digestibility, warrants also further research.

Research on the nutritive value of cactus for ruminants in South Africa is confined to the work of Terblanche *et al.* (1971). These researchers used fresh cactus. Very little research on cactus silage could be found in the available literature. Despite the widespread use of cactus pear in other arid areas of the world, there has been very little applied research locally on their use.

In Chapter 3 the chemical composition of different *Opuntia ficus-indica* cladode varieties, recently available for fruit production was investigated. Chapter 4 deals with the influence of different levels of dry matter (DM) and the inclusion of molasses on the fermentation characteristics of *Opuntia ficu-indica* var. *Fuscicaulis*. The intake and digestibility of *Opuntia* silage by sheep were investigated in Chapter 5.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1. Introduction

According to Rodriguez (1997) prickly pear cactus (*Opuntia*) has been traditionally used as fruit, vegetable and forage. The aim of this chapter is to extensively review literature on the nutritive value and utilization of prickly pear cladodes as animal feed. This entails examining previous and recent work on the utilization of prickly pear cladodes in a fresh, dried or ensiled form. Factors affecting silage quality in general are also reviewed.

#### 2.2. Prickly pear in South Africa

Prickly pear (*Opuntia*) cladode in South Africa has been used by livestock farmers as drought fodder since the 18<sup>th</sup> century when first introduced to the country (Van Sittert, 2002). Barbera (1995) stated that the presence of *Opuntia* was first reported in 1772 in South Africa. According to Brutsch & Zimmermann (1995) as cited by Zeeman (2005) there is some evidence to suggest that originally (at least 250 years ago) only spineless varieties of *Opuntia ficus-indica* were introduced in South Africa and that these have reverted back to the spiny form over a period of nearly 200 years; the spiny forms are considerably more aggressive than the spineless forms and are therefore better adapted to spread.

In South Africa and neighbouring countries, cactus pears find highly favourable environmental conditions. *Opuntias* were first introduced to the Cape region in the seventeenth century. Cactus pears infested about 900.000 ha in the Eastern Cape and the Karoo. Infestations have now been almost completely eliminated with biological control and due to an act, applied to the spiny forms, prohibiting the uncontrolled diffusion of the plants (Barbera, 1995). Barbera (1995) also stated that the spiny forms are still used as a source of forage and fodder, but many initiatives have already been planned in the Ciskei and Karoo regions to increase production by planting spineless cactus pears. At Grootfontein Research Institute at Middelburg, Eastern Cape province of South Africa, 22

spineless cactus pear varieties for use as a livestock fodder crop was introduced in 1914 (De Kock, 1980; Barbera, 1995; Felker, 1995).

Fruit production from *Opuntia* become particularly relevant to town markets during the 1960s, as the traditional business carried out along the roads and based on wild plant harvest was replaced by specific plantations (Brutsch, 1984). Since 1980, the first intensive and specialized plantations have been set up, mostly in the old Transvaal and Ciskei regions. They now cover some 1 500 ha and one of their targets is to reach the northern hemisphere market in a highly favourable period from the business point of view (Barbera, 1995). Production of spineless cactus pear (*Opuntia ficus-indica*) in South Africa for fruit production and export to countries in Europe has recently increased considerably (Claassens & Wessels, 1997). During 2003 more than 465 000 kg of fresh fruits were exported by sea and air from South Africa (Anonymous, 2003).

### **2.3. Prickly pear in other countries**

The literature indicates that this plant has become important for fodder in many parts of the world, where it is utilized as both natural and cultivated populations. It is cultivated in Africa, Italy, US, Mexico, Brazil, Chile and other countries (Barbera *et al.*, 1992; Le Houerou, 1992; Brutsch & Zimmerman, 1995). Large areas are encountered in Algeria, Chile, Mexico and Brazil. It is used all the year round or as emergency feedstock in the case of drought. During drought, cacti remain succulent. In many arid areas the farmers use cactus extensively as emergency forage that is harvested from both wild and cultivated populations to prevent the disastrous consequence of frequent and severe droughts (Le Houerou, 1992).

In the United States, at the beginning of this century, the *O. ficus-indica* selections created by Luther Burbank seemed to lead to a more widespread use of cactus in the diet of both men and animals. Luther Burbank (1911) as cited by Nobel (1988) stated in rather overenthusiastic tones, that the development of the spineless cactus pear promises to be of a great or even greater value to the human race than the discovery of steam (Nobel, 1988).

In Morocco and Algeria, *Opuntias* are utilized as multifunctional plants, and are not specifically cultivated for fruit or fodder. It is most commonly used as fencing around farms and small villages, and as a windbreak. The plants in the fences are also utilized for fruit production and in case of drought, for fodder. Fruits, also collected from wild plantations, are utilized for subsistence and are sold at the local markets (Barbera, 1995).

In many countries, the *Opuntia* fields are small and dense and although the fruits are always eaten by people and sold in the markets, production also for fodder adds to the importance of cultivation. Alternative uses of the fruits are not very diffused. In the other regions of Morocco, the most common use is dried pulp as food for poor people. It is also used for medical purposes. In Mexico, Nopalitos are cladodes of less than one month old, are widely used in traditional Mexican cooking. The breeding of *Dactylopius coccus costa* is also economically important for the production of carmine dye (Barbera, 1995).

#### **2.4. Prickly pear cladodes as drought resistant fodder**

Drought should not be confused with aridity. Aridity rather refers to the mean long-term relationship between rainfall and potential evapo-transpiration. Drought is a usual feature of aridity, although it may occur in non-arid zones. Southern Africa, with its variable and limited rainfall could be regarded as arid, and are seasonal and severe droughts a normal occurrence. During seasonal or severe droughts, considerable stock and losses of production could occur as a result of lack in quality and quantity of fodder (De Kock, 1998).

Although the high moisture content of the succulent spineless cactus pad has disadvantages, spineless cacti can be of inestimable value during dry periods when drinking water becomes scarce. The succulent pads can then serve as sources of drinking water for stock. Experiments have shown that sheep kept in pens can do without water for more than 500 days if they have daily access to sufficient quantities of spineless cactus (Potgieter, 2004). The research results show clearly that water intake is zero when cactus intake by sheep is about 300g of dry matter. Sheep fed for a long period (400 to 500 successive days) with large amount of cactus stopped drinking (Roussow, 1961). Woodward *et al.* (1915) with Jersey cows made the same observation. However, Cottier (1934) as

cited by Felker (1995) suggested that it is not possible to suppress completely water for cattle fed on cactus.

#### **2.4.1. Drought resistant properties**

*Opuntia* are particularly attractive as an animal feed because of its high efficiency in converting water to dry matter (DM) and thus digestible energy (Nobel, 1995). Felker (1995) mentioned that *Opuntia* are not only useful because it can withstand drought, but because its conversion efficiency is greater than C<sub>3</sub> grasses and C<sub>4</sub> broad leaves. The ecological success of *Opuntia* and other cacti is partly a reflection of their daily pattern of carbon dioxide (CO<sub>2</sub>) uptake and water loss, both of which occur primarily at night. Most plants open their stomata, and hence begin taking up CO<sub>2</sub> from the atmosphere, at dawn (Nobel, 1995). These observations relate to a gas exchange pattern, known as Crassulacean acid metabolism (CAM).

The CAM plants, such as *Opuntias*, represent between 6 and 7 % of the nearly 300 000 species of plants (Ting, 1985; Winter, 1985; Nobel, 1991a). Most species of plants (92-93 %) are C<sub>3</sub> plants, whose first photosynthetic product is a 3-carbon compound. Only about 1 % of plant species are C<sub>4</sub> plants. Their first photosynthetic product is a 4-carbon organic acid. These species are quite important ecologically and agronomically and include sugar cane (*Saccharum officinarum*), (*sorghum bicolor*), corn maize (*Zea mays*) and many wild tropical grasses. In comparison with these C<sub>4</sub> crops, as well as with C<sub>3</sub> crops (such as alfalfa, rice and wheat), CAM plants are generally and correctly viewed as very slow growers. This low productivity is however not an inherent characteristic of the CAM pathway. It does not apply to the CAM species *O. ficus-indica*, which is cultivated in about 30 countries for its fruits, young cladodes (used as a vegetable) and mature cladodes (used for forage and fodder) (Russell & Felker, 1987; Nobel, 1988; 1994). Even though water conservation is of critical importance for *Opuntias*, other environmental variables such as temperature, light, nutrients and soil salinity also affect their daily net CO<sub>2</sub> uptake, productivity, reproduction and survival (Nobel, 1995).

The key feature of CAM plants is their succulence, which for *Opuntia* is manifested on a morphological level, by their thick cladodes and on an anatomical level by the large water-filled

vacuoles in their photosynthetic cells and the many layers of water-storage cells. During drought, water is preferentially lost from the water-storage parenchyma which contains relatively tightly packed cells, slightly larger than those in the chlorenchyma (Nobel, 1995).

Adaptation favouring drought resistance also occurs for the epidermis, the single layer of cells on the outer side of the chlorenchyma. The number of stomates per square millimeter is between 10 and 30 for various *Opuntias*, compared with 100 to 300 for the lower sides of leaves of highly productive C<sub>3</sub> and C<sub>4</sub> plants (Conde, 1975; Nobel, 1991b). The epidermis is covered by a waxy water-proofing cuticle that is generally 10 to 50 μm (micrometers) thick for *Opuntias*, On the other hand it is only 0.2 to 2 μm thick for the leaves of C<sub>3</sub> and C<sub>4</sub> plants. Chlorenchyma cells of CAM plants contain vacuoles capable of occupying 90 % or more of cell volume, and in which the organic acids that accumulate during the night are stored. In particular, CO<sub>2</sub> entering through the stomates of *Opuntia* species at night is bound to a 3-carbon compound, phosphoenolpyruvate (PEP), a reaction catalyzed by the enzyme PEP carboxylase. This lead to the formation of a 4-carbon acid, oxaloacetate, rapidly converted to malate (Nobel, 1994).

### **2.5. Feeding value of spineless cactus (*Opuntia ficus-indica*)**

A fresh spineless cactus pad contains approximately 90 per cent moisture and 10 per cent DM (De Kock, 1998; Bonsma & Mare, 1942). The energy requirement for the survival of a 35 kg sheep is approximately 350g of total digestible nutrients (TDN) to supply its energy needs for maintenance. Such sheep would thus have to ingest 538g of dry spineless cactus pads to obtain sufficient energy. This means that 5 to 6 kg of fresh spineless cactus must be ingested. According to De Kock (1998) a sheep can however only consume an average of 4 kg fresh cactus leaves per day. De Kock (1980) stated that the daily TDN requirements for a 400 kg beef cattle are 2 850g. Therefore, such an animal will require approximately 4 385 g of dry cactus to meet its requirements. That means a daily ingestion of 44 to 45 kg of fresh cactus cladodes. The animal only consumes an average of 40 kg of fresh cactus cladodes per day (De Kock, 1980).

De Kock (1983) is of the opinion that one reason why a sheep cannot ingest sufficient spineless cactus pads to supply in its needs, is the high moisture content of the pads. It has been found that

sheep fed on fresh chaffed spineless cactus pads hardly drink any water. In fact they take in more water from the cactus leaves than sheep on a dry ration. The high moisture content of fresh cactus is thus an important limiting factor of cactus intake by sheep.

De Kock (1990) and Ben Salem, *et al.* (1996) mentioned that the protein content of cactus cladodes is very low in general. It has been recommended by De Kock (1980) that any ration for non-reproductive sheep and cattle should contain at least 8% of crude protein. Rations or feeds with low protein content are poorly ingested by animals. A sheep with a live weight of 35 kg requires approximately 50 g of crude protein per day. An average daily intake of 500 g from of cactus cladodes contains only 20 g of crude protein. Therefore cactus cladodes must be supplemented with some form of crude protein to be utilized more efficiently (De Kock, 1980). Potgieter (1995) mentioned that another noticeable deficiencies of cactus pear are the low phosphorus and sodium contents, which can be supplemented with an inexpensive lick consisting of 60 % bone meal and 40 % salt. The positive characteristics of cactus pear as a feed source are its high calcium, carbohydrate (energy) and digestibility (above 70%).

## **2.6. Utilization of spineless cactus**

### **2.6.1. Grazing**

The easiest way to utilize spineless cactus is by direct grazing. It requires very little labour and is thus also the cheapest method (De Kock, 1980). The best method of grazing is to divide the plantation into small paddocks and to graze each of these intensively for a short period. Large losses occur during grazing due to wastage. Direct browsing needs very tight grazing control, otherwise wastage may reach 50 % of the fodder produced (cladodes partially eaten and abandoned) and the plantation itself may be destroyed by over browsing within a short time of overstocking (De Kock, 1980). It is best to utilize spineless cactus in rotation so that a plantation is utilized every three to five years. In this way a plantation can be chopped or grazed each time to the height of one pad higher than the original planting. When spineless cactus are utilized in this manner, the plants recover well, the material available for use is of good quality and the plants are kept within a suitable height range (Nefzaoui & Ben Salem, 1996a).



### **2.6.2. Cut and carry**

Plants are grown in a fenced off area, pruned on an annual or bi-annual basis and fed outside in troughs or merely dumped in a grazing camp for animals to consume. A large intake and thus better utilization can be obtained by chaffing the pads. The ideal size of cubes is approximately 30 mm x 30 mm. It is in fact sufficient if the pads are chaffed in strips approximately 20 to 30 mm wide. In this form the material will dry fairly quickly and wastage is reduced to a minimum (De Kock, 1980). The method which requires the least time and labour is to chaff pads with a mobile chaff-cutter which is transported between the rows in the plantation, and spreads the chaffed material in strips between the rows where the sheep can pick it up. The cut-and-carry technique bears the advantages that the loss of feed is virtually zero and the risk of over-utilization is considerably reduced.

### **2.6.3. Dried pads**

Chaffed spineless cactus pads can be dried on any suitable surface and then ground in a hammer-mill through a 6 mm sieve. In the form of meal, the spineless cactus material is not only ingested better, but are also easier to store and the surplus can thus be stored for use during droughts.

### **2.6.4. Supplementation of spineless cactus**

In an emergency, where nothing else is available, spineless cactus cladodes can be fed alone in any form because sheep and cattle can actually survive on it for a long period. Woolen sheep were kept for 500 days on cactus cladodes alone and survived. For optimal utilization, however, cactus cladodes should be supplemented. As protein is the most important deficiency of spineless cactus, a protein-rich supplement should be supplied. A ration consisting of spineless cactus meal and 6.5 percent fish-meal will supply in all the needs of sheep (De Kock, 1980).

According to De Kock (1980) the most suitable supplement for spineless cactus meal, however, appears to be alfalfa meal or alfalfa hay. A supplementation of 100g of alfalfa in summer and 200g in winter per sheep with spineless cactus meal *ad libitum* is recommended. Any other legume hay with reasonably high protein content can be used instead of alfalfa. Spineless cactus pads can also be used as supplementary feed on Karoo veld. If reasonable quantities of dry veld fodder are still available with the spineless cactus leaves, no additional fodder need be given (De Kock, 1980). Poor

quality roughage may be supplemented with cactus. The intake of straw increased significantly with an increase of the amount of cactus in the diet (Nefzaoui *et al.*, 1993; Ben Salem *et al.*, 1996). Cactus is also a good supplement to ammonia or urea-treated straw, since it provides the soluble carbohydrates necessary for the efficient use of the non-protein nitrogen by microbes in the rumen (Nefzaoui *et al.*, 1993).

### **2.6.5. Silage**

The principle of ensiling is to achieve anaerobic conditions under which natural fermentation can take place. In practice this is achieved by consolidating and compacting the material and the sealing of the silo to prevent re-entry of air. The ensiled product retains a much larger proportion of its nutrients than if the crop had been dried and stored as hay or stover. Silage is most often fed to dairy cattle, because they respond well to highly nutritious diets. Since silage goes through a fermentation process, energy is used by fermentative bacteria to produce volatile fatty acids (VFA), such as acetate, propionate, lactate, butyrate etc, which preserve the forage. The result is that the silage is lower in energy than the original forage, since the fermentative bacteria use some of the carbohydrates to produce VFA. Thus, the ensiling process preserves forages, but does not improve the quality or the nutrient value (McDonald *et al.*, 1991).

#### **2.6.5.1. The basic principles in making silage**

The first essential objective in preserving crops by natural fermentation is the achievement of anaerobic conditions. In practice anaerobiosis can be obtained by various methods. The most efficient way would be to store the material in a hermetically sealed container, and under these conditions, the oxygen, trapped by the herbage, and would rapidly be removed by respiratory enzymes in the plant. The main aim of sealing is to prevent re-entry and circulation of air during storage. When oxygen is in contact with herbage for any period of time, aerobic microbial activity occurs, and the material decays to a useless, inedible, and frequently toxic product.

Silage is moist forage, stored in the absence of oxygen and preserved by acids produced during ensiling. During ensiling, bacteria on the plant ferment plant sugars to produce organic acids (such as lactic and acetic acids) that lower the pH of the silage until bacteria can no longer grow. The silage

remains preserved as long as air is kept out (Kunkle & Chambliss, 2002). A basic principle of ensiling is to provide adequate compaction of the crop to minimize air infiltration (Coetzee, 2000). Generally, ensiling of forage plants is always accomplished by both the anaerobic environment and a bacterial fermentation of sugars, which lower the pH primarily through the production of lactic and acetic acids (McDonald *et al.*, 1991).

The basic principles of silage making from grass are the same for silage making from agri- industry by-products (Bolsen *et al.*, 2002). Firstly attention must be paid to ensure anaerobic conditions and a low pH, i.e. the by-products must be stored air-tight at all times, and secondly, there must be sufficient natural acid in the silage to restrict the activities of undesirable bacteria. Therefore the ensiled material must be rich enough in water soluble carbohydrates.

As a forage crop is cut, harvested and stored, loss of dry matter (quantity) and nutritional quality inevitably occur. These losses are due to enzymes that degrade the plant after it has been cut. Enzymes may originate from the dying plant itself or from bacteria and other micro-organisms (Broderick, 1995). The oxidation of plant sugars by respiratory processes is another attribute that negatively affects fermentation characteristics in the silo (Oude Elferink *et al.*, 1999). Despite the best management of ensiling, some oxygen will remain in the silage, and its presence in silage is one major causes of deterioration (Woolford, 1990). Its presence depends on various factors that influence air penetration into the silage (Rees, 1982).

Delayed sealing has been reported to result in silage of high pH, high butyric acid, high volatile nitrogen, low lactic acid levels and high dry matter losses (Henderson & McDonald, 1979). This aerobic growth rapidly degrades the energy content of the silage, and will often decrease palatability and reduce voluntary intake (Davies, 1993). Severe deterioration will allow the growth of filamentous fungi, which may produce dangerous mycotoxins (Di Costanzo *et al.*, 1995). Mycotoxins are complex organic compounds that are produced by fungus to increase its virulence as a plant pathogen by reducing the ability of the plants resistance (Bullerman, 1986). In contrast, saprophytic (mold or rot) fungi reduce the competitive ability of other fungi or bacteria that are competing for the same food source through the release of these toxins. As these fungi grow, the

nutritive value of the plants they infect or the stored feed they infect is depleted. Available carbohydrates and other nutrients are converted to carbon dioxide and other fungal metabolites not readily available as animal nutrients (Di Costanzo *et al.*, 1995).

Under anaerobic condition, the epiphytic lactic acid bacteria ferment the water-soluble carbohydrates (WSC) in the crop to lactic acid, and to a lesser extent to acetic acid (McDonald *et al.*, 1991). Due to the production of these acids the pH of the ensiled material decreases and spoilage micro-organisms are inhibited. The ensiling process requires several days and can be divided into four phases according to Kunkle & Chambliss (2002).

**Phase 1.** Plant enzymes and aerobic bacteria metabolize plant sugars and oxygen trapped in the packed forage, producing carbon dioxide, water and heat.

The plant tissues continue to live after they are packed in the silo. This phase progresses until the oxygen is depleted, usually 24 hours or less after storage. Silage temperature is elevated 15°C to 20°C or more, depending on the amount of air available.

**Phase 2.** When air is depleted, the anaerobic bacteria ferment plant sugars, producing acetic, lactic, and other organic acids become active. This phase may continue for 2 to 4 days; the organic acids lower silage pH from above 6 to below 5.

**Phase 3.** Once pH is below 4.5 the lactic-acid-producing-bacteria predominate, causing a further reduction in pH. This phase progresses over 2 to 3 weeks; lactic-acid fermentation slows or stops when the fermentable sugars are depleted or the low pH inhibits bacterial growth. For forages with sugar concentrations below 8% of the dry matter, this phase is limited because fermentable sugars are not available.

**Phase 4.** Silage becomes stable and can remain in good quality for long periods if air does not penetrate. If silage pH and moisture are elevated, it is possible that clostridial bacteria (usually inhibited by low pH or low moisture) may grow, degrading silage quality. Clostridial bacteria grow

without oxygen, degrade sugars, and turn lactic acid to butyric acid, thus causing the pH to rise. They also break down protein to amines and other undesirable end products. An insufficient concentration of lactic acid leads to increased decomposition, dry-matter loss, and reduced palatability of silage.

#### **2.6.5.2. Factors affecting silage quality**

Several factors are known to influence the fermentation and preservation of forage that is harvested, stored, and fed as silage. These factors include sugar concentration and buffering of the forage, dry-matter concentration, types of bacteria, temperature during fermentation, rate of harvest, air exposure during harvest, storage, and feeding (Kunkle & Chambliss, 2002).

##### **(i) Water soluble carbohydrates (WSC)**

The amount of water-soluble carbohydrates (WSC) necessary to obtain sufficient fermentation depends on the dry matter content and the buffering capacity of the plant material used (Heinrichs, 1999). The dry matter and protein content is largely unchanged by ensiling, but the WSC is consistently degraded (Rees, 1997). This can be attributed to the action of microorganisms, with the missing WSC either converted to organic acids or fully oxidized, and the length of storage (Mui *et al.*, 2001). Kaiser *et al.* (1999) reported that WSC have been found to be higher in the afternoon than in the morning and the increase is less than 5% of the total WSC (Heinrichs, 1999).

Meeske (1998) indicated that when WSC are limiting, lactic acid bacteria (LAB) will produce less lactic acid and more acetic acid. It is therefore essential that limited amounts of WSC are utilized optimally by homo-fermentative lactic acid bacteria to ensure a rapid drop in pH. In cases where forage has an insufficient amount of WSC, it is difficult to ensile satisfactory (Ash & Elliot, 1991; Kavana *et al.*, 1999; Mushi *et al.*, 2000). Kavana *et al.* (1999) mentioned that as a solution, fresh sugar cane can be used as a WSC additive to produce high quality silage.

Experiments conducted by Catchpoole (1965) demonstrated the effect of a lack in WSC on silage quality. After ensiling a tropical grass containing 0.29% WSC on dry matter basis, the pH was 5.47 and lactic acid content 0.24% of the silage DM. When the same forage was ensiled with 2 % added

sucrose, pH and lactic acid levels were 4.92 and 3.54 %, respectively. Volatile nitrogen content was reduced from 40.3 % to 18.3 % (expressed as a percentage of total nitrogen) by the addition of sucrose. It appears that the added sucrose was certainly stimulatory to lactic acid bacteria. Even though counts of lactic acid bacteria in silage may be low initially, the addition or presence of sufficient soluble carbohydrates will stimulate their multiplication and subsequent lactic acid production (Ohyama, *et al.*, 1973).

Inadequate amounts of WSC in silage crops may result from several causes, such as delayed sealing which promotes oxidation and a reduced WSC content (as much as 50% ) (Ruxton *et al.*, 1975). Other factors such as stage of growth, harvesting techniques, weather and fertilizer applications can affect levels of WSC in ensiled materials (Whittenbury *et al.*, 1967). Research indicated that, with appropriate harvest management and ensiling techniques, a WSC content of at least 2 to 3 % (wet basis) is needed to produce a desirable silage product (Dijkstra, 1960).

#### **(ii) Buffering capacity**

The buffering capacity of forages has an influence on the ease with which the forage can be ensiled. It can be defined as the degree to which forage material resists changes in pH. Forage with a high buffering capacity will be highly resistant to a reduction in pH which is necessary for good preservation (Bjorge, 1996). Therefore more acid must be produced to reduce the pH to desired levels. This is undesirable in silage because more WSC must be used to produce the additional acid. Kung & Shaver (2004) stated that all forages have different buffering capacities. Fresh forages with a high buffering capacity will require more acid to reduce its pH than forage with a low buffering capacity. In general, fresh legumes are well buffered which means that more acid is required to cause changes in the pH of the fermenting material. As a general rule about 10-12 per cent WSC in legumes dry matter will be sufficient for ensiling whereas a minimum of only 6-8 per cent is required for grasses (Bjorge, 1996).

#### **(iii) Moisture content of the forage**

The composition of silage depends upon the material ensiled but the most important controllable factor determining silage quality is the water content. It is usually referred to indirectly as the dry

matter (DM), which is defined as the sum total of the other constituents (including volatile organic components) after wilting (Rees, 1997). Excessive wet silage (> 70% moisture) usually results in fermentation dominated by undesirable butyric acid-forming bacteria, the loss of large volumes of highly digestible nutrients through seepage, and poor animal performance due to low consumption (Mueller *et al.*, 1991). Clostridial-type micro-organisms may also grow in this situation and reduce the quality of silage (Sullivan & Mckinlay, 1998). Meeske (2000) also stated that clostridia are very sensitive to water availability and require wet conditions for active development. The wetter the material the lower the critical pH will be.

The wetter silages are reported to ferment longer than wilted silages and require high WSC levels and lower pH for stability (Kung & shaver, 2004). Generally, the optimum moisture contents for precision-chopped silage are about 65 per cent (Bolsen *et al.*, 2002; Mueller *et al.*, 1991; Bjorge, 1996). Bjorge (1999) also mentioned that a slightly higher moisture may be desirable when long chop lengths are used, when packing is minimal, or when the silage is not well sealed. Less moisture (40 to 50 per cent) is required in some oxygen limiting silos. Although silage may be made within a large range of moisture contents, DM should be over 20 percent to assure good silage quality (Guo *et al.*, 2000).

#### **(iv) Type of bacteria**

The most desirable fermentation will occur where lactic acid producing bacteria is predominate. Although it is frequently assumed that fresh forage is adequately supplied with lactic acid producing bacteria, the number may be low under some circumstances (Bjorge, 1996). The goal of a good fermentation is to maximize the production of lactic acid. Lactic acid is the strongest fermentation acid and most effective in lowering pH. Rapidly dropping pH helps reduce protein breakdown, increases the acid hydrolysis of hemicellulose and slows down unwanted microbial activity. High lactic acid and lactic/acetic ratios indicate that a good fermentation has taken place (Kung, 1996). Muck (1989) stated that lactic acid bacteria begin to dominate the fermentation process after silage pH drops to 5.5 - 5.7 (from 6.5 - 6.7 at ensiling time).

Some species of lactic acid bacteria produce only lactic acid, they are called homofermentative bacteria. However, other species of lactic acid bacteria, called heterofermentative bacteria, producing lactic acid and other end products such as acetic acid, alcohol (ethanol) and carbon dioxide. Homofermentative species are preferable in silage because they produce more lactic acid, which is stronger and reduces pH more than acetic acid. Actually, as pH drops, lactic acid becomes the predominant end product of fermentation. Proper lactic acid production depends on the number of lactic acid bacteria present at the time of ensiling; the presence of a sufficient amount of fermentable sugars and the absence of oxygen in the silage (Satter *et al.*, 1988).

#### **(v) Temperature**

When microbial growth occurs in silage, there is a rise in temperature. In general, the greater the growth rates of micro-organisms, the higher the temperature. It is known that the rate of acidification is greater when silage temperatures are higher and that the onset of fermentation is earlier (Bjorge, 1996). Higher temperatures encourage the growth of undesirable clostridia which result in increased butyric acid and ammonia formation which is detrimental to quality. The optimal temperature during fermentation is below 37,8°C. The higher temperatures results in poor quality silage even though the silage may be palatable (Kunkle & Chambliss, 2002). Under-heated silage gives a drab green colour, strong aroma, slimy soft tissues, insipid taste, and a pH of about 5.0. Over-heated silages, frequently referred to as heat damaged, range colour from brown to dark brown and have a charred hay or tobacco aroma (Bjorge, 1996). The digestibility of protein has been found to be reduced in the presence of oxygen and high temperatures. The longer the heating the more the protein damage. Also, the rate of damage increases with temperature (Harris, 2003). Kunkle & Chambliss (2002) also stated that heating appears to not only decrease the availability of protein to animal but also reduce the availability of carbohydrates.

#### **(vi) Compaction**

The physical condition of the ensiled material is one of the factors that govern the extent in which compaction will success. Chopped or bruised crop will compacts better, free sap and cell juices and places the ensiled material at the disposal of *lactobacilli* and leads to a better fermentation (Meiring, 1967). Chopping alone may not guarantee a successful fermentation since the materials need to be



packed and sealed. Anaerobic fermentation is facilitated by good compaction, whereby an inadequate compaction may result in aerobic fermentation giving undesirable silage that is high in ammonia, butyric acid and low lactic acid with pH higher than 4.2 (Mushi *et al.*, 2000). The ease with which ensiling material is compacted depends on the moisture content of forage. Forage with high moisture content is more likely to result into high seepage, which is associated with high nutrient loss. In contrast, forages with insufficient moisture content, will not pack well either and more air will be left in the silage resulting in a moldy silage (Etgen & Reeves, 1978).

Pressure in silages resulting from compaction leads to a discontinuation of aerobic respiration. Meiring (1967) reported that compaction have little or no influence on the biological and chemical changes in silage, but having a marked effect upon the environmental conditions within the mass. In addition, Mushi *et al.* (2000) reported a decrease in pH with an increase in the applied compression force during ensiling. This means that the degree of compaction governs both the amount of air in the silage and the amount and the rate of effluent loss. The compaction pressure applied immediately after filling, results in a check to intracellular fermentation with its tendency to produce acetic acid, and that there is more sugar left for the desirable lactic acid organisms which results in better quality silage. With a higher degree of compaction, a higher density is obtained which in turn will cause a greater restriction of the flow of air through the silage (Mushi *et al.*, 2000).

The filling rate of the ensiled material have a large effect on the total length of the aerobic phase of ensiling that starts with the first load of chopped crop. Coetzee (2000) reported lower levels of acid detergent insoluble nitrogen (ADIN) in bunkers that were filled faster than those filled slower. Ensiling generally results in an acid detergent fibre (ADF) increase. Smaller increases in ADF were found with shorter filling periods, which were associated with lower silage pH, an indication of good preservation (Coetzee, 2000).

#### **(vii) Silage additives**

Fermentation in the silo can be a much uncontrolled process leading to less than optimal preservation of nutrients. Silage additives have been used to improve the ensiling process (better energy and DM recovery) with subsequent improvements in animal performance (Kung, 2001).

Bolsen (1995); Muck & Kung (1997) stated that, silage fermentation is a dynamic process that is affected by variety of factors and silage additives have been classified into various categories that generally include 1) stimulants of fermentation (microbial inoculants, enzymes, fermentable substrates), 2) inhibitors of fermentation (acids, other preservatives), and 3) nutrient additives (ammonia and urea). In order for a silage additive to be useful it must increase DM (nutrient) recovery, improve animal performance (milk quantity and/or composition, gain, body condition & reproduction), decrease heating and molding during storage (Kung & Muck, 1997).

According to Keady (1996) molasses has been used as a fermentation stimulant for many years and is a by-product of the sugar-cane sugar-beet industries and contains 79% soluble carbohydrates; of which the main component is sucrose (45 to 50%). Anhydrous ammonia as well as water- or molasses- ammonia mixes have been used as silage additives. Ammonia additions have resulted in an addition of an economical source of crude protein (Huber *et al.*, 1979); prolonged bunk life during feeding (aerobic stability) (Britt & Huber, 1975); less molding and heating during ensiling and decreased protein degradation in the silo (Johnson *et al.*, 1982). However historically, silage have been successfully made using mixtures of organic (formic, propionic, citric, etc.) acids and mineral acids or organic acids alone (Perez, 1995).

The use of direct addition of organic and /or mineral acids is very unlikely to be a means by which resource poor farmers could process feed materials due to the cost and danger of handling strong acids in low technology situations (Wilkinson & Phillips, 1979). However, biological additives are regarded to be more advantageous over chemical additives because they are safe and easy to use, non-corrosive to machinery, do not pollute to the environment and are regarded as natural products (Muck, 1988). These additives are added to silage in order to stimulate lactic acid fermentation, accelerating the decrease in pH, and thus improving silage preservation. Research has shown that suitable fast acid-producing strains in sufficient number may be effective as a silage additives provided that dry matter and water soluble carbohydrates of the crop are high enough (Seale, 1986). For maximum fermentation speed, bacteria should start growing immediately, grow fast and produce an abundance of lactic acid.

McDonald (1981) stated that good silage can be made without additive treatment, but the numbers of LAB present on growing crops can be extremely small and therefore silage additives can be beneficial in such circumstances. According to Chin (2002) the quality of silage is one of the parameters that will determine successful silage use and the inclusion of additives as well as other treatments like chopping, have been found to improve the fermentative quality of Napier grass silage (Shinoda *et al.*, 1999). As various additive types have different modes of action (Kung & Ranjit, 2001; Megias *et al.*, 1998), no one is currently ideal for all circumstances (Muck, 1996; O'Kiely, 2001). Muck (1996) mentioned that there are three factors appear to be crucial for the variation in using inoculants for the fermentation process namely, the natural abilities of the bacteria involved, the number of bacteria applied and their viabilities and the stability of the inoculants when used on a farm.

Weinberg & Muck (1996) mentioned that as a guide, if additives are to be used, they need to be chosen carefully and appropriately, and applied properly. The main purpose of using an additive is to make a profit from the investment. Consequently, it should be decided if the technical and or biological benefits that may accrue from the use of an additive will result in an economic return. Some additives like *L. buchneri* have the ability to convert lactic acids to acetic acids and improve the aerobic stability in silages (Driehuis *et al.*, 1999). The application of nitrate is good in inhibiting clostridial growth during the onset of fermentation (Spoelstra, 1983) and some of the additives can work as fermentation aids instead of stabilizing silages (Sanderson, 1992)

The condition of the ensiled material may also impact the success of inoculants. For example, Filya *et al.* (2000) compared inoculated fresh wheat silage with wilted wheat silage and found that inoculation improved the fermentation in wilted silage more than in the fresh silage. Therefore the effect of any additive on the type of material to be ensiled should be understood. Megias *et al.* (1998) indicated that the use of additives during ensiling is to ensure an efficient fermentation process so that high quality silage can be produced without animal health or handling related problems and without negative effects on the rumen fermentation as a result of these additives. Many studies have experienced poor silage qualities during the feeding phases or exposure to air.

Therefore, there was a need to introduce silage additives when insufficient viable LAB was present on the ensiling material at harvest to ensure rapid homofermentative fermentation during ensiling.

McDonald (1981) stated that insufficient viable LAB will cause a delay in the drop of pH of plant material after ensiling, increase nutrient losses and poor palatable silage. Inoculants can be used to ensure that sufficient viable lactic acid bacteria are present (Woolford, 1984). Although moist crops carry a sufficient population of natural bacteria to produce silage, there is no control over the type of acid produced or how long the fermentation process takes place. Therefore, inoculation allows the farmer to control the fermentation by adding bacteria that produce appropriate acids in the fastest possible time. There are also reports stating that if the raw material has a high concentration of LAB, inoculants will not be important in improving the fermentation process (Deshmukh & Patterson, 1997). In addition, low LAB on initial crops in cooler weather may be limiting the rate of initial pH decline, resulting in less effective preservation. Inoculants applied to crops in warmer weather would not be expected to provide as great a level of additional preservation because LAB populations are already likely to be higher and carbohydrates may not be available for additional conversion to acid (Coetzee, 2000).

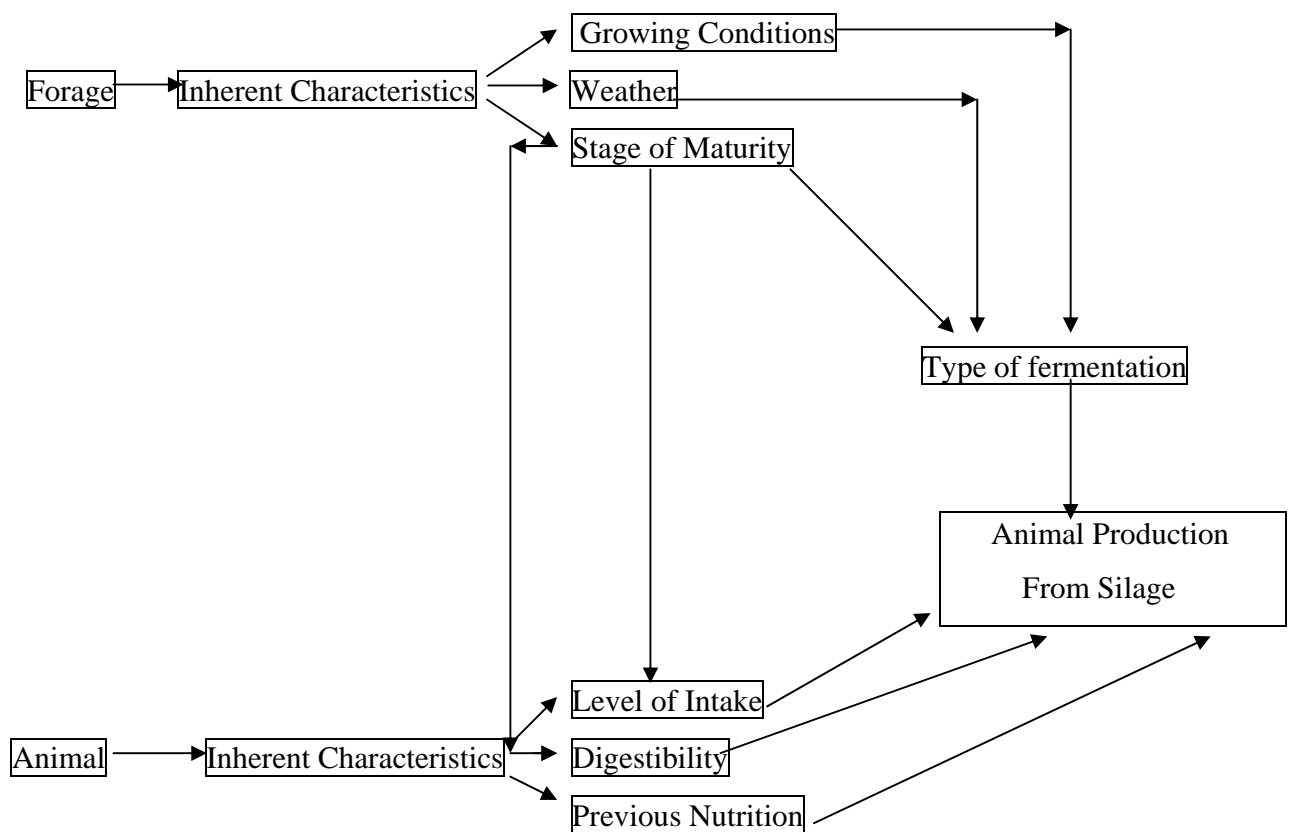
Tropical forages that are low in WSC are difficult to ensile satisfactory without additive (Ash & Elliot, 1991; Kavana *et al.*, 1999). Therefore, only those materials with high levels of WSC, such as sugar and fruit products are likely to be able to produce sufficiently high levels of acid by fermentation to assist in the storage of non-fermentable substrates (Machin, 1999). After all, the success of any additive depends on adequate substrate and its population relative to the natural bacteria on the forage (Muck, 1988), and the natural ability of the organisms to produce high levels of lactic acid across the full pH range of crop preservation (McDonald, 1981).

Lactic acids are relatively strong and their production in silo causes pH to drop, which is essential in the rush to kill-off less desirable organisms before they consume valuable nutrients and dry matter (McDonald *et al.*, 2002). Acetic and propionic acid producing bacteria are also used because of their antifungal activities, but their use often results in substantial in-silo losses and higher final pH. Although highly acetic silage may show some resistance to aerobic spoilage (Weinberg *et al.*, 1999),

both acetic and butyric acids are associated with bad smelling silage with low palatability and intake. Therefore, the type of acid produced has a major impact on speed of preservation and the palatability of the resultant silage (McDonald, 1981).

### 2.6.5.3. Factors affecting silage utilization

Factors affecting silage utilization can be considered in terms of the purpose of silage production. Since silage is a method for preserving feed for livestock, the success of the process must be considered in terms of the efficiency of preservation and the usefulness of the end product as animal feed. Within this stated purpose, methods of evaluation and factors affecting silage preservation can be established and evaluated. The primary factor affecting animal performance is the feeding value of the crop at time of ensiled (McCullough, 1978). The majority of silages will lose some feeding value during the ensiling process. The major factors influencing animal production from silage are illustrated in Figure 2.



**Figure. 2. Factors affecting silage utilization (McCullough, 1978)**

The two primary factors influencing animal performance are dry matter intake and dry matter digestibility of silage. McCullough (1969) using oat silages varying in dry matter digestibility from 56 to 68%, found that 89 % of the variation in average daily gain of growing dairy heifers was explained by dry matter digestibility of the silage and dry matter intake. Using similar silages, McCullough (1978) was able to explain 93% of the variation in milk production in dairy cows by measuring TDN (Total Digestible Nutrients) intake, body weight and percent TDN in silage dry matter. In addition to the general factors affecting stage of maturity at harvest, there are several recognized if poorly understood effects of geography and weather on plant growth and suitability for ensiling. It has long been recognized that crops grown in hot climates are less digestible than crops grown in cool climates (McCullough, 1978).

#### **2.6.5.4. Silage quality**

The production of poor quality silages is a widespread problem and the energy and feeding value losses are of a large magnitude. In a normal silage fermentations, ensiling is the preservation of wet crops with organic acids, principally lactic acid, produced by the fermentation of available carbohydrates under anaerobic conditions (Crawshaw, 1977). The first objective of a normal fermentation requires that anaerobic conditions are achieved rapidly and maintained, and the second objective is to develop a sufficiently low pH to prevent the proliferation of undesirable microorganisms (McDonald *et al*, 1973). The chemical and microbiological characteristics of normal silages include high lactic acid levels relative to the levels acetic and butyric acids, low pH, low content of ammonia and volatile nitrogen, and low numbers of spore forming anaerobes (Langston *et al.*, 1962). Physical criteria often used to distinguish normal silage are green colour, pleasant smell and good texture (Neumark *et al.*, 1964).

The research literature agrees that poor quality silage usually exhibit comparatively large numbers of spore forming anaerobes (Kempton & San Clemente, 1959; Langston *et al.*, 1962), the most numerous being of genera clostridia (Bryant *et al.*, 1952 ; Gibson *et al.*, 1958). Clostridia are most sensitive to osmotic pressure and require very wet conditions for active growth (Whittenbury *et al.*, 1967). Generally, silage having dry matter (DM) contents less than 30 to 35 % is especially prone to

clostridial fermentation (Gouet *et al.*, 1965). Both saccharolytic and proteolytic types of clostridial fermentations occur in silages (Bryant *et al.*, 1952; Watson & Nash, 1960; Whittenbury *et al.*, 1967). Saccharolytic clostridial activity is characterized by DM losses during ensiling (due to CO<sub>2</sub> production) and the presence of butyric acid. The presence of non-volatile amines (e.g., putrescine, histamine and tyramine), ammonia, and branched chain fatty acids (isobutyric and isovaleric acids) in silage are useful indicators of proteolytic clostridial activity.

It is important to emphasize that the presence of butyric acid in silage has no apparent adverse effect on the ruminant animal (Woolford, 1975). McDonald *et al.* (1973) stated that two main microbiological criteria of successful preservation are inhibition of clostridia and fungi. Molds and yeasts belong to the fungi and are quite distinct from bacteria. Yeasts are able to grow either aerobically or anaerobically and survive and proliferate in silage. They compete with the lactic acid bacteria for readily available carbohydrates (Ruxton & McDonald, 1974).

Undesirable fermentation due to clostridia (butyric acid bacteria), grow in the absence of oxygen (anaerobic) and are normally found in soil and manure. The fact that clostridia live in the absence of oxygen and resist pH as low as 4.2 allows them to compete with lactic acid bacteria even after the pH drops below 5.0. Essentially, clostridia dominates the fermentation when lactic acid bacteria do not produce enough lactic acid to drop pH to a stabilization value fast enough (Leibensperger & Pitt, 1987). Clostridia tend to grow faster at temperature of about 35<sup>0</sup>C (a higher optimal temperature than most previously discussed bacteria). Thus this type of undesirable fermentation happens when extensive respiration and enterobacterial fermentation occur and silage temperature rise in early phases of the fermentation process (Pitt, 1990).

Wattiaux (1999) stated that some species of clostridia ferment sugars and change the lactic acid produced by lactic acid bacteria into butyric acid, carbon dioxide and hydrogen (H<sub>2</sub>). Production of carbon dioxide and hydrogen gas indicates a loss of digestible energy. The breakdown of lactic acid into butyric acid, which is a weaker acid, means that the pH of silage going through clostridial fermentation will tend to rise. Butyric acid has a strong, repulsive smell. Trace amount of butyric acid suffice to decrease voluntary intake by cows. Some species of clostridia ferment amino acids, leading

to the formation of toxic substances such as cadaverine and putrescine. Silage spoiled by clostridia is easily recognizable due to its strong odor, a pH above 5.0, ammonia nitrogen greater than 10 % of total nitrogen and more butyric acid than lactic acid (Wattiaux, 1999)

Silage intake has received more attention, based on literature reports, than any other silage-related topic. Pertinent to this fact is that intake of an ensiled crop is considerably less than the intake of the same crop non-ensiled. Decreases in feed intake have been reported with ensiled high-moisture grains (Prigge *et al.*, 1976). Researchers have attributed this reduction in silage intake to variety of causes like low DM content of the ensiled material (Conrad, 1971), silage pH or free acidity (King, 1943; Thomas & Wilkinson, 1975), increased osmolarity of ruminal liquor (Ternouth, 1967), products of protein breakdown (Clancy *et al.*, 1977; Neumark *et al.*, 1964). decreased rate of passage of silage from the rumen because of changes in ruminal motility (Clancy *et al.*, 1977) and decreased rate of ruminal fermentation (Bergen *et al.*, 1974; Fujita & Katsumata, 1975; Hawkins *et al.*, 1970; McCullough & Sisk, 1969).

Limit research regarding cactus silage could be found in the available literature. Castra *et al.* (1977) conducted a study to investigate spineless cactus silage as a ruminant feed and concluded that cactus silages can be useful resource for animal producers in the arid or semi-arid regions during dry seasons.



## CHAPTER 3

### CHEMICAL COMPOSITION OF DIFFERENT *OPUNTIA FICUS-INDICA* CLADODES VARIETIES

#### 3.1. INTRODUCTION

The *Opuntia* plant's attributes makes it ideal "drought insurance" as it is adapted to withstand severe drought conditions and still produce fodder at a low cost. The cactus pear (*Opuntia*) can also be used in agri-forestry systems with legumes and annual crops. Cactus pear can play a stabilizing role in agriculture as it can prevent stock losses during droughts, save natural grazing from over-grazing, increase farm income and alleviate poverty in rural areas (Potgieter, 1993). Rodriguez (1997) mentioned that traditionally, prickly pear cactus has been used as fruit, vegetable and forage. The use of *Opuntia* as a source of food for domestic animals and wildlife has been very important in the arid and semi-arid regions. Although it has been considered poor in terms of nutrient and fibre and it is often the only source of green forage in the dry season capable of providing vitamin A precursors which is the significant advantage for animal feed.

In general *Opuntias* are considered to be high in water content, high in *in-vitro* digestibility and low in crude protein content. There is however a lack of information regarding the nutritional value of different *Opuntia ficus-indica* cladode varieties currently under investigation and used for fruit production. Therefore a laboratory study was under taken to investigate the nutritional value of different *Opuntia* varieties from chemical analysis.

#### 3.2. Materials and Methods

##### 3.2.1. Sampling

One year old cladodes from six different varieties of *Opuntia ficus-indica* were randomly harvested in five replicates. The harvesting of one year old cladodes avoided the confounding effect of age. Furthermore one year old cladodes are usually pruned in winter. These cladodes varieties (*Castello*, *Chicco*, *Fusicaulis*, *Montery*, *Morado* & *Rubasta*) were obtained in June 2006 from a plant production study at Grootfontein Agricultural Development Institute, Middelburg, Eastern Cape

Province, South Africa. Cladodes were cut into 20 mm square pieces using a sharp knife. The samples of the six different *Opuntia ficus-indica* cladodes varieties and five replicates were dried in a force draught oven at 100°C to a constant mass, moisture determined and milled through a laboratory mill with a one millimeter sieve. The dried plant material was stored in tightly sealed plastic bottles for later chemical analysis.

### **3.2.2. Chemical analysis**

All chemical analysis was carried out in duplicate for each variety and replicate sample. The dry matter (DM), ash and ether extract content of different samples were determined according to the methods described by AOAC (1984). Crude protein (CP) was determined using the Dumas method of combustion with a LECO FP2000. The factor of 6.25 was used to convert the N content of the samples to CP. The acid detergent fibre (ADF) and neutral detergent fibre (NDF) contents were determined according to the procedures described by Robertson & Van Soest (1981). Lignin was determined according to the method of Goering & Van Soest (1970). Cellulose and hemicellulose were determined by difference from ADF, NDF and lignin. Non fibre carbohydrates (NFC) was calculated by difference whereby the sum of NDF, CP, EE and ash in percentage are subtracted from 100 (Mertens, 1992; Sarwar *et al.*, 1992; Varga & Kononoff, 1999; NRC, 2001). Ether extract (EE) content was determined according to the methods described by Official Methods of Analysis of the AOAC (1965). Minerals were determined according to the methods described by Fiske & Subbarow (1961).

### **3.2.3. Statistical analysis**

The SAS (1995) procedure for analysis of variance (PROC-ANOVA) was used to test for significant differences between the varieties. A complete randomized design was used. Dependant variables that were found to be significantly different ( $P < 0.05$ ) were further subjected to multiple comparison test using Tukey's test.

## **3.3. Results and Discussion**

The average chemical composition of different *Opuntia ficus-indica* cladode varieties are presented in Table 3.

**Table 3 - The average chemical composition of different *Opuntia ficus-indica* cladode varieties on a dry matter basis.**

<b>Variety</b>	<b>DM</b> (%)	<b>ASH</b> (%)	<b>OM</b> (%)	<b>CP</b> (%)	<b>ADF</b> (%)	<b>NDF</b> (%)	<b>Cellulose</b> (%)	<b>Hemi – cellulose</b> (%)	<b>Lignin</b> (%)	<b>NFC</b> (%)	<b>EE</b> (%)	<b>P</b> (%)	<b>K</b> (%)	<b>Ca</b> (%)	<b>Mg</b> (%)	<b>Na</b> (%)
<b>CASTELLO</b>	8.61 <sup>b</sup> ± 0.06	22.65 <sup>a</sup> ± 0.54	77.35 <sup>b</sup> ± 0.54	6.12 <sup>b</sup> ± 0.08	17.36 <sup>a</sup> ± 0.46	19.87 <sup>b</sup> ± 2.46	14.84 <sup>a</sup> ± 0.25	4.51 <sup>c</sup> ± 1.25	2.51 <sup>a</sup> ± 0.02	48.64 <sup>a</sup> ± 0.23	2.41 <sup>a</sup> ± 0.03	0.19 <sup>a</sup> ± 0.03	2.86 <sup>a</sup> ± 0.14	2.31 <sup>a</sup> ± 0.28	3.48 <sup>a</sup> ± 0.19	0.03 <sup>a</sup> ± 0.01
<b>CHICCO</b>	10.61 <sup>a</sup> ± 0.36	22.97 <sup>a</sup> ± 0.02	77.03 <sup>b</sup> ± 0.53	4.61 <sup>d</sup> ± 0.17	15.48 <sup>b</sup> ± 0.16	35.98 <sup>a</sup> ± 0.91	4.95 <sup>c</sup> ± 0.29	10.5 <sup>b</sup> ± 1.05	20.52 <sup>b</sup> ± 0.02	34.28 <sup>b</sup> ± 0.24	2.36 <sup>ab</sup> ± 0.02	0.17 <sup>a</sup> ± 0.01	2.95 <sup>a</sup> ± 0.17	2.03 <sup>a</sup> ± 0.17	3.91 <sup>a</sup> ± 0.32	0.05 <sup>a</sup> ± 0.01
<b>FUSICAULUS</b>	8.97 <sup>b</sup> ± 0.08	22.34 <sup>a</sup> ± 0.25	77.66 <sup>ab</sup> ± 0.25	5.48 <sup>bc</sup> ± 0.13	13.66 <sup>c</sup> ± 0.31	24.93 <sup>b</sup> ± 2.71	2.42 <sup>d</sup> ± 0.29	11.27 <sup>b</sup> ± 2.5	11.22 <sup>c</sup> ± 0.03	45.41 <sup>c</sup> ± 0.07	1.94 <sup>d</sup> ± 0.01	0.19 <sup>a</sup> ± 0.01	3.03 <sup>a</sup> ± 0.08	2.51 <sup>a</sup> ± 0.28	3.33 <sup>a</sup> ± 0.24	0.04 <sup>a</sup> ± 0.01
<b>MONTERY</b>	8.57 <sup>b</sup> ± 0.06	20.21 <sup>a</sup> ± 0.49	79.79 <sup>a</sup> ± 0.49	5.29 <sup>c</sup> ± 0.16	17.04 <sup>a</sup> ± 0.34	38.52 <sup>a</sup> ± 1.33	4.31 <sup>c</sup> ± 0.4	12.73 <sup>a</sup> ± 1.19	21.48 <sup>b</sup> ± 0.04	33.37 <sup>b</sup> ± 0.34	2.18 <sup>bc</sup> ± 0.04	0.18 <sup>a</sup> ± 0.02	2.87 <sup>a</sup> ± 0.19	2.22 <sup>a</sup> ± 0.19	3.42 <sup>a</sup> ± 0.21	0.03 <sup>a</sup> ± 0.01
<b>MORADO</b>	8.92 <sup>b</sup> ± 0.32	24.07 <sup>a</sup> ± 0.48	75.93 <sup>b</sup> ± 0.48	8.08 <sup>a</sup> ± 0.23	13.81 <sup>c</sup> ± 0.11	22.71 <sup>b</sup> ± 1.11	6.85 <sup>c</sup> ± 0.17	8.89 <sup>b</sup> ± 1.12	8.87 <sup>d</sup> ± 0.18	42.49 <sup>d</sup> ± 0.21	2.39 <sup>a</sup> ± 0.07	0.19 <sup>a</sup> ± 0.03	3.14 <sup>a</sup> ± 0.21	2.25 <sup>a</sup> ± 0.21	3.84 <sup>a</sup> ± 0.31	0.03 <sup>a</sup> ± 0.01
<b>RUBASTA</b>	9.09 <sup>b</sup> ± 0.16	22.94 <sup>a</sup> ± 0.66	77.06 <sup>b</sup> ± 0.66	3.66 <sup>e</sup> ± 0.11	16.04 <sup>ab</sup> ± 0.23	22.89 <sup>b</sup> ± 2.09	9.23 <sup>b</sup> ± 2.1	6.85 <sup>b</sup> ± 0.23	6.84 <sup>d</sup> ± 0.04	48.43 <sup>a</sup> ± 0.18	2.10 <sup>dc</sup> ± 0.03	0.16 <sup>a</sup> ± 0.02	3.27 <sup>a</sup> ± 0.19	2.39 <sup>a</sup> ± 0.26	3.45 <sup>a</sup> ± 0.24	0.04 <sup>a</sup> ± 0.01
<b>Means</b>	9.13 ± 0.16	22.53 ± 0.30	77.47 ± 0.30	5.5 ± 0.29	15.56 ± 0.32	27.48 ± 1.63	6.82 ± 0.61	9.13 ± 3.26	11.81 ± 0.06	42.11 ± 0.21	2.23 ± 0.04	0.18 ± 0.01	3.02 ± 0.07	2.29 ± 0.09	3.57 ± 0.11	0.04 ± 0.01
<b>P</b>	0.0001	0.0014	0.0014	0.0001	0.0001	0.0001	0.0001	0.023	0.0001	0.0001	0.0001	0.92	0.5	0.8	0.5	0.63
<b>cv</b>	4.64	4.49	1.31	5.46	3.78	13.8	8.89	35.72	1.73	6.81	3.49	23.59	11.25	20.62	14.39	44

<sup>a,b,c,d</sup> = Means in column with different alphabetic superscripts differ significantly (P<0.05), (± se)

cv = Coefficient of variation

### **3.3.1. Dry matter**

The highest ( $P < 0.05$ ) average DM content of 10.61 % was observed for the *Chicco* variety. Griffiths & Hare (1906) indicated that out of all *Opuntia* species analyzed *Opuntia imbrica* had the highest DM content. The average DM content (9.13%) of different *Opuntia* varieties investigated in this study was generally low. This was however quite similar to those reported by Hoffman & Walker (1912); Woodward, *et al.* (1915) and Nefzaoui & Ben Salem (1998).

The different varieties of *Opuntia* cladodes analyzed in this study contain a high average moisture content of 90.87 % which could hamper the dry matter (DM) intake by animals. Several researchers found that animals consume more DM in the form of hay compared to wet material (Pasha, *et al.*, 1994). The intake of DM can therefore probably be increased if the fresh cladodes are wilted or dried before feeding.

Furthermore the high water content of the cactus cladodes makes it a bulky feed and therefore, poses a real problem when it has to be transported over long distances. On the other hand Gonzalez (1989) mentioned that *Opuntia* is one of the main water sources for animals. Watering animals during summer and drought periods is a serious challenge in arid regions. Animals use a lot of energy to reach water holes, and rangeland degradation in the area surrounding watering points is common. Feeding with cactus cladodes supply additional water in dry areas. Nefzaoui & Ben Salem (1998) showed that water intake from free available water is zero when daily cactus consumption by sheep is about 300g of dry matter.

### **3.3.2. Ash**

Ash is the remaining residue after all organic matter present in a sample is completely incinerated (Maynard, 1979). It comprises of all inorganic matter in the feed, as well as inorganic contaminants such as soil and sand.

The results in Table 3 indicated that there were no significant differences ( $P > 0.05$ ) in ash content between different *Opuntia* varieties. The ash content of the *Opuntia* varieties in the current study varied between 20.21 to 24.07% and compared very well with the values reported in the literature. Ash values which varied from 17.19 % to 27.41 % on DM basis were reported by Griffiths & Hare

(1906); De Kock (1965); Teles (1978) and Nefzaoui & Ben Salem (2002). These results supported the observations of Nefzaoui & Ben Salem (1996a) that the ash content of cactus cladodes is remarkably high. Nefzaoui & Ben Salem (2002) was of the opinion that the high ash content is a result of its high calcium (Ca) content. According to Table 3 this was not the case in the present study. In fact magnesium (Mg) showed the highest value in the *Opuntia* cladodes, followed by potassium (K).

### **3.3.3. Organic matter**

From Table 3 it is evident that the highest ( $P < 0.05$ ) organic matter (OM) content was recorded for the *Montery* variety. The OM content of the different *Opuntia* cladodes varieties analyzed in this study vary from 75.93 % to 79.79 % of DM. This is similar with the range that was reported in the literature (Ben Salem *et al.*, 1996; Nefzaoui & Ben Salem, 2002; Ben Salem *et al.*, 2002; McMillan *et al.*, 2002; Batista *et al.*, 2003; Zeeman, 2005).

### **3.3.4. Crude protein**

Crude protein (CP) is a gross measure of the nitrogen (N) contained in a feedstuff. It is assumed that the nitrogen is derived from protein containing 16 % N and by multiplying the N figure by 6.25 an approximate crude protein value is obtained (Ruddell *et al.*, 2002).

According to the results shown in Table 3 the CP content of the different *Opuntia* cladodes varied between 3.66% – 8.08 % on a DM basis. The *Morado* cactus variety showed the highest ( $P < 0.05$ ) and the *Rubasta* cactus variety the lowest crude protein content. The statistical significant ( $P < 0.05$ ) differences in the CP content of the different *Opuntia* varieties that occurred, could be attributed to genetic differences as the environment (soil, fertilization, and climate) was the same for all the *Opuntia* species in this study.

Tegegne (2001) reported the lowest CP content for *O. engelmannii* variety (3.32 %) and the highest for *O. stenopetala* (8.84 %). Pretorius *et al.* (1997) found that the CP content of the Algerian variety was markedly higher (6.82 %) than the other *Opuntia* varieties used in their trial. These variations in CP content of different *Opuntia* varieties could also be due to factors like soil, fertilization and

climate. With the exception of the *Morado* variety the crude protein contents of all the other varieties were too low to maintain sufficient microbial growth.

Consequently the low protein content will also inhibit the ingestion of spineless cactus pears, resulting in a low intake of energy. Pretorius, *et al.* (1997) also indicated that the main criticism against cactus cladodes as animal feed is that its CP content is too low for maintenance. On the other hand recent studies have shown that the CP content of some varieties is 9.2% (Sirohi *et al.*, 1997) even over 11% (Gregory & Felker, 1992). This is high enough for sufficient microbial growth. Generally positive responses to protein supplementation are expected with forages contain less than 6-8% CP (Gregory & Felker, 1992).

### **3.3.5. Acid detergent fibre**

According to Van Soest (1967) fractionating procedure, acid detergent fibre (ADF) represents essentially the crude lignin and cellulose fractions of plant material including silica.

The results in Table 3 indicated that the ADF content of the different *Opuntia* varieties used in this study varies significantly ( $P < 0.05$ ) from 13.66% (*Fusicaulis*) to 17.36% (*Castello*) with an average of 15.56 %. The highest ( $P < 0.05$ ) ADF content was recorded for *Castello* and *Montery*, followed by *Rubasta* and *Chicco*, and the lowest for *Morado* and *Fusicaulis*. Ben Thlija (1987) reported an average value for ADF of 15.89 % for *O. engelmannii*, *O. filipendula*, *O. versicolor*, *O. polyacantha* and *O. fragilis* on a dry matter basis. This is similar with the average ADF content recorded in this study. According to Scholtz (2001) the average ADF content of *Medicago sativa* hay (Lucerne) is 39.98 % of DM in South Africa. According to the low ADF content of *Opuntia* varieties it could not be regarded as a sole roughage source.

According to McDonald *et al.* (1995) the ADF is negatively correlated with overall digestibility thereby lowering the amount of energy potentially available to the animal. According to this *Morado* and *Fusicaulis* seems to be the superior varieties from an energy point of view.

### 3.3.6. Neutral detergent fibre

Neutral detergent fibre (NDF) is predominantly consisting of cell wall or structural carbohydrates. NDF gives a close estimate of fibre constituents of feedstuffs as it measures cellulose, hemicellulose, lignin, silica, tannins and cutins. These components give plants rigidity and enable the plant to support itself as it grows. Cellulose and hemicellulose can be partially break down by microbes in the rumen to provide energy to the animal (Schroeder, 1994).

According to the results in Table 3 the average NDF content of different *Opuntia* varieties was 27.48 % of DM and varies significantly ( $P < 0.05$ ) from 19.87 % (*Castello*) to 38.52% (*Montery*). Ben Thlija (1987) reported an average NDF content of 34.11 % for *O. engelmannii*, *O. filipendula*, *O. versicolor*, *O. polyacantha* and *O. fragilis* on a DM basis which is relatively higher than the NDF content observed in this study. The average NDF content found in this study is relatively higher than 24.39 % of Algerian reported by Zeeman (2005) on a DM basis. Compared to the mean of NDF contents of lucerne and barley hay of 55.6 % and 45.15 % of DM reported by Ben Salem *et al.* (1994) and Nefzaoui & Ben Salem (2002) respectively, the NDF contents of the different *Opuntia* varieties in this study were relatively low. This is again an indication that *Opuntia* could not be regarded as a sole roughage source.

The NDF contents of *Castello*, *Fusicaulis*, *Morado* and *Rubasta* were statistically significant ( $P = 0.0001$ ) lower compared to *Chicco* and *Montery* varieties. The NDF content of a feed is negatively correlated with digestibility and intake (Ruddell *et al.*, 2002) and could the lowest energy intake be expected for the latter two mentioned varieties.

### 3.3.7. Cellulose

Cellulose is a principal constituent of the cell wall of plants. It is most abundant in the more fibrous feeds. It is generally low in digestibility and may reduce the digestibility of other nutrients. Cattle, sheep, and horses digest cellulose fairly effectively and only slightly digested by hogs (Cullison, 1975). The cell wall material contains other ingredients, and recent evidence suggests that there

might be a chemical linkage between cellulose and hemicellulose as well as between cellulose and lignin.

According to the results in Table 3 the average cellulose content of different *Opuntia* varieties was 6.82 % of DM and varies significantly ( $P < 0.05$ ) from 2.42 % (*Fusicaulis*) to 14.84 % (*Castello*). Ben Thlija (1987) reported a range of cellulose content of 7.95 % (*O. engelmannii*) to 13.73 % (*O. versicolor*) which is lower than the range of cellulose content in this study. From the results in Table 3 it was clear that the average cellulose content of *Opuntia* varieties were lower than that of alfalfa (21.29 %) (Ben Thlija, 1987).

### **3.3.8. Hemicellulose**

Hemicellulose is defined as alkali-soluble cell wall polysaccharide which is closely associated with cellulose. It has been mentioned by McDonald *et al.* (1991) that the name hemicellulose is misleading and implies erroneously that the material is destined for conversion to cellulose. Structurally, it is said to be composed mainly of D-glucose, D-galactose, D-mannose, D-xylose and L-arabinose units joined together in different combinations and in various glycosidic linkages and they may also contain uronic acids.

In Table 3, the hemicellulose content of different *Opuntia* varieties varies significantly ( $P < 0.05$ ) from 4.51 % (*Castello*) to 12.73 % (*Montery*) on DM basis, lower than the range reported by Ben Thlija (1987), whereby the hemicellulose content of *Opuntia* varieties analyzed varied from 12.74 % (*O. polyacantha*) to 20.87 % (*O. versicolor*). The average hemicellulose content of *Opuntia* varieties in this study was 9.13 % and also lower than that of lucerne (15.24 %) (Ben Thlija, 1987).

### **3.3.9. Lignin**

Lignin is an indigestible plant component and it is the prime factor influencing the digestibility of plant cell wall material negatively. It is a NDF component of the forage together with hemicellulose and cellulose (Schroeder, 2004). Fibre, measured as neutral detergent fibre (NDF), usually accounts for 30-80% of the organic matter in forage crops and ruminants which depends on microbial fermentation, are well-adapted to use plant fibre for energy. A higher NDF level in the forage is



related to a higher lignin content and consequently a low digestibility and forage intake (Schroeder, 2004).

From the results in Table 3 it is clear that the highest ( $P<0.05$ ) lignin content was recorded for *Chicco* and *Montery* varieties. Accordingly these varieties are potentially has the lowest digestibility and energy values. *Castello* variety showed the lowest ( $P<0.05$ ) lignin content as compared to other *Opuntia* varieties analyzed in this study.

### **3.3.10. Non fibre carbohydrates**

A non-fibre carbohydrate (NFC) is a non-cell wall fraction consisting of the highly digestible cell contents such as starch, sugars and pectins. NFC is a highly digestible energy source and is needed together with degraded protein, for microbial growth and digestion. According to Russell *et al.* (1992) NFC fractions are fermented by ruminal bacteria that can utilize either ammonia or peptide as a nitrogen source.

The results in Table 3 showed that the NFC content of different *Opuntia* varieties varies significantly ( $P<0.05$ ) from 33.37 % (*Montery*) to 48.64 % (*Castello*) on a DM basis. The *Castello* (48.64%) and *Rubasta* (48.43%) varieties showed the highest ( $P<0.05$ ) and *Chicco* (34.28%) and *Montery* (33.37%) varieties the lowest NFC content with *Fusicaulis* (45.41%) and *Morado* (42.49%) in between. It is however evident from the results in Table 3 that the NFC content of *Fusicaulis* was significantly higher ( $P<0.05$ ) than that of *Morado*. These values are in agreement with the conclusion from the NDF and lignin values that *Chicco* and *Montery* varieties showed potentially the lowest energy values.

From the results in Table 3 it was clear that the NFC content of *Opuntia* varieties were lower than that of barley (65%) and maize (75%) on a DM basis (Dupchak, 2005). On the other hand the NFC content of *Opuntia* varieties studied were relatively higher than good quality roughages such as maize silage (29 %) and lucerne hay (midbloom) (24 %) on a DM basis (Dupchak, 2005). According to these values, *Opuntia* varieties could be in general rated as an energy source ranging between a concentrate and roughage.

### **3.3.11. Ether extract**

Ether extract (EE) is also known as crude fat (CF) which comprises of all substances that are soluble in ether. Although EE contain lipids, which provide energy it will also include other fat-soluble substances such as chlorophyll and fat-soluble vitamins. However, too much fat in the ration lowers feed intake of the ruminant and disturbs functioning of the rumen (AOAC, 1990).

The ether extract contents of the different *Opuntia* varieties are shown in Table 3. The average EE content of different *Opuntia* varieties was 2.23 % on a DM basis. The values varies significantly ( $P < 0.05$ ) from 1.94 % (*Fusicaulis*) to 2.41 % (*Castello*). These results were relatively higher than the results reported by Griffiths & Hare (1906); Fuentes *et al.* (1991), where the EE values differed from 1.62 to 2.09 % on a DM basis. This was also higher than the 1.66 % DM reported by Zeeman (2005) for *Opuntia ficus-indica* var. Algerian. Wilson & Brigstocke (1981) reported that fat levels in the diet should not exceed 8 % of DM, otherwise fibre digestion is impaired. It is clear that the fat level of *Opuntia* is too low to impair rumen fermentation.

### **3.3.12. Minerals**

The results shown in Table 3 reflect that there was no statistical significant differences ( $P > 0.05$ ) in phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) nitrogen (N) and sulfur (S) contents between the different varieties evaluated. According to Tegegne (2001) the main mineral components in *Opuntia* ashes are calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na), usually found as salts and silica. Accordingly in the current study Mg, K and Ca were the main mineral components as already mentioned.

#### **3.3.12.1. Phosphorus**

Phosphorus plays an important role in energy metabolism, bone and teeth formation. It also serves as a component of protein in the soft tissues (Maynard *et al.*, 1979).

The average phosphorus content of the different *Opuntia* varieties was 0.18 % of DM, which was in the same range of 0,1 – 0,5 % reported by Lopez *et al.* (1988) as cited by Tegegne (2001) and higher than the 0,11 % (*O. ficus-indica*) reported by Azocar & Rojo (1991), as cited by Tegegne (2001). It

was however lower than the 0,2 %; 0,33 % and 0,55 % reported for *O. ficus-indica*, *O. engelmannii* and *O. lindheimeri* respectively (NRC, 1968; Nefzaoui *et al.*,1995). These differences in P content of different studies could probably be explained and influenced by factors like cultivars, soil fertilization, cladode age, rainfall, irrigation, temperature and planting sites (Lopez *et al.*, 1988, as cited by Tegegne, 2001).

### **3.3.12.2. Potassium**

Potassium (K) is required for the osmotic pressure regulation and water balance, electrolyte balance, acid-base balance, muscle contraction and nerve impulse conductor (Maynard *et al.*, 1979).

The average potassium (K) content of different *Opuntia* varieties in the present study was remarkably high (3.02 % on a DM basis). This K level was relatively the same as the 3.04 % (*O. engelmannii* & *O. lindheimeri*) ported by Hoffman & Walker (1912). It was however higher than the 0.37 % and 1.09 % (*O. ficus-indica*) as reported by Noble (1983), De Kock (1965) and Teles (1978). The high K level obtained in this study might be explained by the young cladodes used. Retamel *et al.* (1987b) mentioned that age of cactus cladodes has a significant effect on K content and the younger the cladodes the higher the K content.

### **3.3.12.3. Calcium**

Calcium (Ca) is found mostly in the cell wall of the cacti. It was also found as oxalate crystals and druses (Gibson & Nobel, 1986). It is also participating in ATP and phospholipids hydrolysis and is responsible for bone and teeth formation, blood coagulation and transmission of nerve impulses (McDonald *et al.*, 1991).

From Table 3 it is clear that the Ca content of *Opuntia* varieties analyzed were high and exceeded beef and cattle as well as sheep requirements(0.18-0.66 % of DM)(NRC, 1989). The results in Table 3 indicated that the average Ca content of the different *Opuntia* varieties used was 2.29 % on a DM basis. This was higher than the 1.03 % (*O. ficus-indica*) reported by Tegegne (2001) and 2.01 % (*O. ficus-indica*) reported by Azocar (1991) as cited by Tegegne (2001). It was however lower than the average Ca of 8,66 %; 3,0 % and 2,66 % reported by Nefzaoui & Ben Salem (1998); Gonzalez

(1989) and Lopez *et al.* (1988 ) as cited by Tegegne (2001) respectively. The high Ca content of the *Opuntia* cladode species could probably be attributed to the accumulation of high quantities of Ca in its pads due to high Ca compounds in soils and the young age of *Opuntia* cladodes used in this study. Nefzaoui & Ben Salem (1998) stated that the high level of calcium in *Opuntia* species could be attributed to the fact that cactus cladodes have a high oxalates content of 13 %, of which 40 % is in a soluble form which are probably bound to calcium.

#### **3.3.12.4. Magnesium**

Magnesium (Mg) is also associated with Ca and P in the metabolism of blood and plays a part as enzymes activator and neuromuscular transmissions. It is found in skeletal tissue and bone and plays a role in proteins, fats and carbohydrate metabolism (McDonald *et al.*, 1996).

Retamel *et al.* (1987b) mentioned that Mg content of *Opuntia* species is high and significantly ( $P < 0.05$ ) increased with age. The average Mg content of different *Opuntia* varieties used in the current study was 3.57 % of DM. This is higher than the 0.11 % and 2.5 % on a DM basis reported by ARC (1965) and Retamal *et al.* (1987b) respectively. McDonald *et al.* (2002) mentioned that the Mg in the food is poorly absorbed from the alimentary canal of ruminants. In some cases only 50 g/kg of the herbage magnesium can be utilized by the ruminant. This low absorbability is further aggravated by potassium. Potassium reduces the efficiency of absorption by inhibiting the two active transport systems in the rumen wall which carry magnesium against the electrochemical gradient. In this regard the high K content of *Opuntia* could influence the absorption of Mg detrimental in the rumen.

#### **3.3.12.5. Sodium**

Sodium (Na) is also responsible for acid-base balance, muscle contraction and nerve transmission. It is required for glucose uptake and amino acid transport (McDonald *et al.*, 1996).

According to the results in Table 3 the average Na content of different *Opuntia* varieties in this study was 0,04 % of DM. This was relatively the same as the results (0.05% Na on DM basis) reported by De Kock (1965) for *O. ficus-indica*. These results were also similar to those reported in other

countries. The low Na content of *Opuntia* species could be explained by the young cladodes used in this study. Retamel *et al.* (1987b) reported that age has an effect on the level of Na, the younger the cladode the lower the Na content. Norton (1982) and Retamel *et al.* (1987b) also mentioned that the low Na content of *Opuntia* was probably due to the low genetic capacity for accumulation, low requirements for growth or low availability in the soil. It is clear from the low Na values that supplementation is necessary when *Opuntia* is fed.

### **3.4. Conclusion**

It seems from the results of the present study that the moisture content of *Opuntia* cladodes and especially the *Chicco* variety was exceptionally high. Accordingly it could influence the dry matter and nutrient intake of productive animals detrimental. However during drought it could serve as a valuable water source and energy source for maintenance of animals.

The CP content of the *Opuntia* cladodes was in general low. With the exception of the *Morado* variety, protein supplementation would be necessary to ensure sufficient microbial growth and digestion of cladodes for maintenance purposes. According to the fibre fractions (NDF & lignin) and NFC values, *Montery* and *Chicco* varieties would result in the lowest energy intake. It further seems that *Opuntia* cladodes is high in ash and especially the minerals, Mg, K and Ca. The high Mg content could be an explanation of the laxative effect associated with the feeding of *Opuntia* cladodes. In general *Opuntia* cladodes could be classified as a high moisture energy source with an energy level ranging between that of roughages and concentrates with a low CP and high Mg, K and Ca content. The dry matter intake and digestibility of cladodes would however eventually determine its nutritional value as an animal feed.

## CHAPTER 4

### THE FERMENTATION CHARACTERISTICS OF *OPUNTIA FICUS-INDICA* var. *FUSICAULIS*

#### 4.1. Introduction

The use of *Opuntia* cladodes as a drought feed has been studied extensively by researchers in South Africa (SA) and abroad. *Opuntia* cladodes and other spineless cactus plants which are used for animal feeding are easy and cheap to grow and can withstand prolonged droughts. Such characteristics make these species a potentially important feed supplement for livestock, particularly during periods of drought and seasons of low feed availability (Shoop *et al.*, 1977).

The spineless cactus fruit industry in South Africa has increased in recent years. This resulted in fresh cladodes to be available as feed when the plants are pruned to stimulate fruit production. These pruned cladodes are to a large extent considered to be waste material. Since many farmers are not primarily livestock farmers, the available fresh material can not be utilized as fresh feed in a relative short period of time. As observed in Chapter 3 spineless cactus pear cladodes contains a high water content. Therefore it is also not economical and practical to transport this bulk material to livestock farmers that may have a need for additional feed. This problem could be solved by drying the cladodes. This is however a time consuming process if sunlight is used or expensive when artificially dried for instance by means of a ventilated oven. The drying of cladodes is also hampered by mucilage around the leaves which is commonly described as water soluble pectin-like polysaccharide (Cárdenas *et al.*, 1997). Although the precise function of the mucilage in cactus pear is not known, it is generally believed to help retain water in cactus (Sudzuki Hills, 1995). The ability of cactus to retain water under unfavorable climate conditions of prolong drought is *inter alia* due to the water binding capacity of the mucilage (Mindt *et al.*, 1975).

Ensiling is the alternative manner to preserve and store *Opuntia* cladodes as livestock feed. De Kock (1980), Nefzaoui & Ben Salem (1996a), Castra *et al.* (1977) and Potgieter (1993) are of the opinion that good silage can be made from cactus cladodes by chaffing them with oat straw, low grade

alfalfa or any other dry roughage on the basis of 84 parts mass of cactus cladodes and 16 parts of roughage, with the addition of molasses meal. When cladodes bearing fruit are used for silage, the addition of molasses is not necessary.

From these suggestions it seems that a low sugar and high moisture content of *Opuntia* could hamper the effective fermentation and preservation of fruitless cladodes. No research on the effect of these factors on the fermentation characteristics of *Opuntia* cladodes could be found in the available literature. Therefore the aim of this study was to investigate the influence of moisture and sugar (molasses) content on the fermentation characteristics of *Opuntia* cladode silage.

## **4.2. Materials and Methods**

### **4.2.1. Ensilage**

One year old *Opuntia* cladodes, var. *Fusicaulis*, were randomly harvested during June 2004 from a field at Grootfontein Agricultural Development Institute, Middelburg, Eastern Cape Province, South Africa. The cladodes were cut into 20 mm square pieces by hand using a sharp, long bladed knife (Figure 4.1). The cladode square pieces were packed in a single layer, on net-wired racks and sun-dried in a glass house. This procedure facilitates air movement between and around the pieces and the net-wired racks. The glass house promotes the faster drying of the *Fusicaulis* cladodes. *Fusicaulis* pieces were also turned regularly to prevent them from moulding.

*Fusicaulis* pieces were sun-dried to obtain four levels of dry matter (DM) namely 10, 20, 30 and 40 percent. Drying *Fusicaulis* pieces to a required DM level was depended on the day-by-day temperatures and the availability of the sun. Four levels of molasses powder (Kalorie 3000) namely 0, 8, 16 and 24 percent on a DM basis were added to each DM level and thoroughly mixed. Approximately three kilograms of each mixture was ensiled into three liter square plastic bottles, tightly packed, weighed and air-tightly sealed (Figure 4.2). For each treatment six replicates were ensiled. The 96 plastic bottles with ensiled cladodes were kept closed at room temperature for 90 days (Figure 4.3).



**Figure 4.1 - *Fusicoulis cladodes* cut into 20mm square pieces**





**Figure 4.2 - Ensiled *Fusicoulis cladodes***



**Figure 4.3 - Plastic bottles with ensiled cladodes**

#### **4.2.2. Sampling procedure**

The total of 96 bottles were opened in a period of two days. Twelve silage bottles from each of the four treatments were opened per day. The content of each bottle were thoroughly mixed before an aliquot sample of each bottle was taken for chemical analysis of the silage. An aliquot of 60g silage in each bottle was sampled, placed in stomacher bags and 360ml of distilled water added. This was left to homogenize for two days and the suspension filtered through a silk cloth. The filtrate was used to determine pH, water soluble carbohydrates (WSC), volatile fatty acids (VFA) and lactic acid (LA) (Meeske, 2000). The rest was used to determine dry matter (DM), acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein (CP) and ether extract (EE).

### **4.2.3. Chemical analysis**

The same procedures for DM, CP, ADF, NDF and EE analysis as described in Chapter 3 were used. The *in vitro* dry matter digestibility (IVDMD) was determined according to the two-phase technique described by Tilley & Terry (1963) as modified by Engels & Van der Merwe (1967). The volatile fatty acid (VFA) was determined using a Carlo Erba 4200 gas chromatograph. Water soluble carbohydrates were determined by the phenol-sulphuric acid method according to Dubois *et al.* (1956). Lactic acid was determined by the colorimetric method of Barker & Summerson (1941). An electronic pH meter was used to determine pH and the gross energy (GE) was determined on a DM basis by using an adiabatic bomb calorimeter (AOAC, 2000).

### **4.3. Statistical analysis**

Data was statistically analyzed as a 4x4 factorial fully randomized block design (effect of 4 DM levels and 4 molasses levels) with 6 replicates. Data were subjected to PROC ANOVA using the General Linear Model (GLM) procedure of SAS Institute (1996).

## **4.4. RESULTS AND DISCUSSIONS**

### **4.4.1. Dry matter (DM)**

The DM content of *Fusicaulis* silage at different levels of DM and molasses inclusion is presented in Table 4.1. A significant DM x molasses interaction occurred. It is clear that the actual dry matter values were lower than the initial desired values. The reason for this could be the production of water during fermentation (Schroeder, 2004; Kunkle, *et al.*, 2006). According to McDonald *et al.* (2002) aerobic fermentation that occurs at the early stages, resulted in the oxidation of sugars via the tricarboxylic acid cycle to carbon dioxide and water. This production of water could however, not explain the all of the observed lower DM content of the ensiled material.

**Table 4.1 The dry matter (DM) content of *Fusicaulis* silage (means ± se)**

Molasses (%)	DM (%)				DM (p)	Mol (p)	Interaction (p)	CV (%)
	10	20	30	40				
0	8.98 ± 0.24 <sup>a1</sup>	17.81 ± 0.19 <sup>b1</sup>	25.63 ± 0.32 <sup>c1</sup>	27.63 ± 0.32 <sup>d1</sup>	0.0001	0.29	0.0001	8.5
8	8.82 ± 0.53 <sup>a1</sup>	18.17 ± 0.15 <sup>b1</sup>	22.69 ± 0.21 <sup>c2</sup>	25.47 ± 0.07 <sup>d2</sup>				
16	7.12 ± 0.26 <sup>a2</sup>	17.44 ± 0.22 <sup>b2</sup>	20.32 ± 0.15 <sup>c3</sup>	23.47 ± 0.11 <sup>d3</sup>				
24	7.35 ± 0.33 <sup>a1</sup>	17.23 ± 0.28 <sup>b2</sup>	20.04 ± 0.11 <sup>c3</sup>	23.23 ± 0.38 <sup>d3</sup>				

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

Another reason for the lower DM content after ensiling could be attributed to the method used to determine the DM of the silage. In the present study DM was determined according to AOAC (1984) by means of oven drying. According to Dewar & McDonald (1961) silage DM cannot be estimated accurately by oven-drying because some of the products of fermentation namely volatile fatty acids are lost. The dry matter obtained in this way under estimates the value by between 0.2 and 0.1 %, the latter being reached in very wet silage (De Brouwer *et al.*, 1991). McDonald *et al.* (2002) is however of the opinion that significant losses of volatile material may take place. Oven drying is also unsuitable for liquid products such as molasses, because sugars at high temperature become caramelised and volatiles other than water will be loss and skin will be form on the surface, preventing quantitative water loss (UK-FSAR, 1982).

According to Haigh (1987) the DM content of silage could extensively influence the pH and LA content. Snyman *et al.* (1990) indicated that, in general, silage ensiled at a low moisture content (54,5%) exhibited depressed fermentation characteristics in terms of pH, TVFA and LA. Seglar (1999) indicated that the reduction of DM result in heterofermentative anaerobes convert WSC into various fermentation end-products at the expense of energy. Although considerable biochemical changes occur during fermentation, the overall dry matter and energy losses arising from the activities of LAB are low. The energy losses, because of the formation of high-energy compounds such as ethanol, are even less (McDonald *et al.*, 2002).

The lower DM content of the ensiled plant material was more obvious with an initial higher desired DM content. In spite of the factors already discussed, it is clear that the initial desired DM levels were not obtained. Therefore the effect of DM on the results of the present study only refers to the DM content shown in Table 4.1. The general high moisture content recorded in cladode silage after ensiling could influence fermentation and dry matter intake detrimental by animals. In this regard Snyman *et al.* (1990) stated that a high moisture content (76.3 %) in silage resulted in an increased fermentation activity. According to Wilkinson *et al.* (1976) it is known that an increase in fermentation activity as well as a shift to undesirable fermentation will suppress DM intake. From Table 4.1 it is evident that statistical significant ( $P=0.0001$ ) differences exist between the actual DM values (Treatments) after the ensiling period. It is further seems from Table 4.1 that the inclusion of increasing levels of molasses was associated with a non significant decline ( $P=0.29$ ) in the DM content of the silage. Although non significant, it is unexpected since the opposite results should occur where molasses was added at increasing levels to the cladodes before ensiling.

#### 4.4.2. Chemical composition

The chemical composition of the *Fusicaulis* silage at different DM and molasses levels are presented in Table 4.2 – 4.5. A significant DM x molasses interaction occurred for ADF, NDF,

**Table 4.2 - The acid detergent fibre content (dry matter basis) of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Acid detergent fibre (%)								
Molasses (%)	DM (%)				DM (p)	Mol (p)	Interaction (p)	CV (%)
	10	20	30	40				
0	21.48 $\pm$ 1.68 <sup>a1</sup>	16.91 $\pm$ 0.46 <sup>b1</sup>	16.12 $\pm$ 0.35 <sup>b1</sup>	15.43 $\pm$ 0.3 <sup>c1</sup>	0.001	0.001	0.0001	14.6
8	19.5 $\pm$ 2.73 <sup>a1</sup>	16.75 $\pm$ 0.5 <sup>b1</sup>	15.44 $\pm$ 0.44 <sup>c1</sup>	15.26 $\pm$ 0.5 <sup>c1</sup>				
16	17.88 $\pm$ 0.89 <sup>a2</sup>	16.11 $\pm$ 0.32 <sup>b1</sup>	15.73 $\pm$ 0.4 <sup>b1</sup>	14.84 $\pm$ 0.42 <sup>c2</sup>				
24	16.18 $\pm$ 2.1 <sup>a2</sup>	16.1 $\pm$ 0.4 <sup>a1</sup>	15.66 $\pm$ 0.3 <sup>a1</sup>	14.62 $\pm$ 0.9 <sup>b2</sup>				

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly ( $P<0.05$ )

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly ( $P<0.05$ )

**Table 4.3 - The neutral detergent fibre content (dry matter basis) of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Neutral detergent fibre (%)								
Molasses (%)	DM (%)				DM (p)	Mol (p)	Interaction (p)	CV (%)
	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>				
0	24.25 $\pm$ 1.2 <sup>a 1</sup>	18.69 $\pm$ 0.4 <sup>b 1</sup>	18.3 $\pm$ 0.53 <sup>b 1</sup>	17.53 $\pm$ 0.2 <sup>b 1</sup>	0.001	0.001	0.001	15.06
8	23.82 $\pm$ 1.2 <sup>a 1</sup>	17.8 $\pm$ 0.5 <sup>b 1</sup>	17.2 $\pm$ 0.4 <sup>b 1,2</sup>	17.1 $\pm$ 0.32 <sup>b 1</sup>				
16	21.6 $\pm$ 2.9 <sup>a 2</sup>	17.3 $\pm$ 0.62 <sup>b 1,2</sup>	16.82 $\pm$ 0.31 <sup>b 2</sup>	16.04 $\pm$ 0.33 <sup>b 1</sup>				
24	20.07 $\pm$ 2.7 <sup>a 2</sup>	16.69 $\pm$ 0.56 <sup>b 2</sup>	16.49 $\pm$ 0.5 <sup>b 2</sup>	15.97 $\pm$ 0.9 <sup>b 1</sup>				

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

**Table 4.4 - The crude protein content (dry matter basis) of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Crude protein (%)								
Molasses (%)	DM (%)				DM (p)	Mol (p)	Interaction (p)	CV (%)
	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>				
0	7.54 $\pm$ 0.14 <sup>a 1</sup>	6.21 $\pm$ 0.02 <sup>b 1</sup>	6.15 $\pm$ 0.26 <sup>b 1</sup>	5.67 $\pm$ 0.27 <sup>b 1</sup>	0.001	0.014	0.0005	7.68
8	7.69 $\pm$ 0.32 <sup>a 1</sup>	6.66 $\pm$ 0.11 <sup>b 2</sup>	6.36 $\pm$ 0.09 <sup>c 1</sup>	5.75 $\pm$ 0.09 <sup>d 1</sup>				
16	6.85 $\pm$ 0.12 <sup>a 2</sup>	6.83 $\pm$ 0.04 <sup>b 2</sup>	6.42 $\pm$ 0.1 <sup>c 1</sup>	5.81 $\pm$ 0.07 <sup>d 1</sup>				
24	6.93 $\pm$ 0.34 <sup>a 2</sup>	6.89 $\pm$ 0.02 <sup>a 2</sup>	6.48 $\pm$ 0.07 <sup>b 1</sup>	6.32 $\pm$ 0.24 <sup>b 2</sup>				

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

**Table 4.5 - The ether extracts content (dry matter basis) of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Molasses (%)	Ether extract (%)				DM (p)	Mol (p)	Interaction (p)	CV (%)
	DM (%)							
	10	20	30	40				
0	2.43 $\pm$ 0.16 <sup>a1</sup>	1.29 $\pm$ 0.02 <sup>b1</sup>	1.11 $\pm$ 0.11 <sup>bc1</sup>	0.92 $\pm$ 0.06 <sup>c1</sup>	0.001	0.001	0.001	16.2
8	1.76 $\pm$ 0.08 <sup>a2</sup>	1.33 $\pm$ 0.07 <sup>b1</sup>	0.54 $\pm$ 0.03 <sup>c2</sup>	0.53 $\pm$ 0.03 <sup>c2</sup>				
16	1.49 $\pm$ 0.06 <sup>a2</sup>	0.86 $\pm$ 0.04 <sup>b2</sup>	0.45 $\pm$ 0.05 <sup>c2</sup>	0.44 $\pm$ 0.02 <sup>c2</sup>				
24	1.46 $\pm$ 0.07 <sup>a2</sup>	0.77 $\pm$ 0.06 <sup>b3</sup>	0.44 $\pm$ 0.01 <sup>c2</sup>	0.38 $\pm$ 0.06 <sup>c3</sup>				

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

CP and EE content. This indicated that the effect of molasses in a specific DM level and or the effect of DM in a specific molasses level differ. It is evident that a higher DM content in the silage were characterized with a lower (P<0.05) ADF, NDF, CP and EE content. Accordingly the inclusion of molasses resulted in a lower (P<0.05) ADF, NDF, and EE content. The effect of adding molasses on the concentration of these nutrients is to be expected. Molasses have a low concentration of these mentioned nutrients and will result in a dilution effect.

#### 4.4.2.1. Acid and Neutral detergent fibre (ADF & NDF)

The results regarding the ADF and NDF content of *Fusicaulis* silage at different DM levels were in agreement with that of Snyman *et al.* (1990). These researchers also found that maize silage with high initial moisture content (76.3 %) contained a significantly (P<0.01) higher ADF concentration (37.75 vs 29.95 %) than that of silage ensiled at the recommended stage of maturation (66 %). A lower moisture content of 54.5 % resulted in the lowest ADF content (28.22 %). Snyman *et al.* (1990) gave however no explanation for this positive moisture x ADF relationship in maize silage. According to McDonald *et al.* (2002) hydrolysis of hemicelluloses during ensilage could occur, liberating pentoses which may be fermented to lactic and acetic acid by most types of LAB. This could contribute to a lower NDF content in lower moisture *Fusicaulis* cladode silage (actual value of  $\pm$  17 % DM and higher) as observed in this study. The significant effect of moisture on the ADF and NDF content of silage is however difficult to explain.

The reduction of ADF and NDF could lead to an increase in digestibility and dry matter intake because both ADF and NDF content in the feed according to McDonald *et al.* (1973) had a negative correlation with digestibility and intake respectively. Mertens (1992) is of the opinion that although the rate of digestion and intake are related to the concentration of NDF in ruminant foods, physical form of the cell wall also affect intake.

The ADF and NDF content of the cladode silage in the present study (Table 4.2 and 4.3) were higher than the 8.07 and 6.48% found by Çürek & Özen (2001) for young and old cladode silage respectively. Factors like climate, age of cladodes and varieties could be responsible for these different results.

#### **4.4.2.2. Crude protein (CP)**

Silage making change the protein fraction of forages (Snyman, 1990). Respiration is responsible for protein breakdown. As plant cells die after cutting, proteolytic enzymes break down large proteins into smaller soluble compounds including peptides, amino acids and ammonia. In addition, enterobacteria have proteolytic enzymes that remain active even after the pH has dropped to 5.0. Thus most of the protein degradation that takes place in a silo occurs within the first 24 to 72 hours (Phase 1 and 2 of silage fermentation). Wattiaux (1999) indicated that a rapid drop in pH is desirable to reduce the amount of protein breakdown in a silo. Nevertheless, recent research indicates that as much as half of the total nitrogen in alfalfa silage may be in the form of non-protein nitrogen. Some scientists have proposed the use of ammonia content as one indicator of adequate silage fermentation (Haigh, 1987).

The CP content of *Fusicaulis* silage at different DM and molasses levels is presented in Table 4.4. The lower CP content of the cladodes silage at higher DM levels, was supported by the finding of Snyman (1990) with maize silage. Snyman observed a small decrease in CP and a concomitant increase in the true protein content of low moisture silage. The influence of DM level in silage on true protein content was however not investigated in the present study. With the exception of the 10% DM treatment, the higher molasses levels in *Fusicaulis* cladode silage resulted in a higher



( $P < 0.05$ ) CP content. This was contrary to the results reported by Van Man & Wiktorsson (2006) that the incorporation of molasses in the silage led to reduced CP content, especially at the higher levels of molasses added. The results of the current study are confusing as the CP content at molasses is low and should an increasing molasses level result in a lower CP content in the silage.

#### **4.4.2.3. Ether extract (EE)**

The ether extract (EE) content of *Fusicaulis* silage at different levels of DM and molasses inclusion is presented in Table 4.5. As already stated, a higher DM and molasses in *Fusicaulis* cladode silage resulted in a lower ( $P < 0.05$ ) EE content. No plausible reason can be offered for the lower EE content, at higher DM levels. The absence of EE in molasses could contribute to the decline in EE with and increasing molasses levels. According to Van der Merwe & Smith (1991) the fat content of feeds is the unstable part. The EE content of *Opuntia* silage was however probably too low to cause any problems during ensiling. The EE content of *Opuntia* silage in the current study corresponds approximately with the 2.33 % reported by Çürek & Özen (2001).

#### **4.4.3. Volatile fatty acid (VFA)**

According to Sim *et al.* (1962) and Van Aldrichem (1963) good silage is characterized by a high lactic acid coupled with a low acetic acid content and the absence of butyric acid. Bryant & Lancaster (1970) are of the opinion that the minimum amount of butyric acid and maximum amount of acetic and lactic acid are a good measure of good quality silage. Van der Merwe (1978) indicated that initially small amounts of volatile fatty acids and mainly acetic acid are formed. As soon as anaerobic conditions exist great amounts of lactic acid are produced which act as preservative of the plant material. If not enough lactic acid is produced to inhibit further micro-biochemical reactions (17 to 21 days), further reactions could occur through the operation of butyric forming organisms on the residual carbohydrates. This reaction resulted butyric acid production. Such a silage is characterized by an unpleasant rotten butter smell (Sim *et al.*, 1962). It does not only make the silage unpalatable but it is also an indication of undesirable fermentation processes in the silage which reduce the feeding value.

#### 4.4.3.1. Acetic acid (AA)

The AA content of *Fusicaulis* silage at different levels of DM and molasses inclusion is presented in Table 4.6. No significant ( $P=0.973$ ) DM x molasses interaction occurred. It is clear

**Table 4.6 - The acetic acid content (dry matter basis) of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Acetic acid (%)									
Molasses (%)	DM (%)				Mean	DM (p)	Mol (p)	Interaction (p)	CV (%)
	10	20	30	40					
0	13.1 $\pm$ 1.15	18.69 $\pm$ 5.02	26.17 $\pm$ 3.67	29.49 $\pm$ 3.18	21.86 $\pm$ 2.12 <sup>1</sup>	0.001	0.034	0.973	31.7
8	14.47 $\pm$ 1.44	22.41 $\pm$ 4.01	26.89 $\pm$ 2.52	37.45 $\pm$ 2.06	25.3 $\pm$ 2.14 <sup>2</sup>				
16	16.52 $\pm$ 1.12	23.14 $\pm$ 4.46	27.58 $\pm$ 5.74	38.49 $\pm$ 2.38	26.43 $\pm$ 2.45 <sup>2 3</sup>				
24	20.11 $\pm$ 2.61	26.37 $\pm$ 2.11	28.2 $\pm$ 2.94	39.72 $\pm$ 4.02	28.59 $\pm$ 2.04 <sup>3</sup>				
<b>Mean</b>	16.05 $\pm$ 0.96 <sup>a</sup>	22.65 $\pm$ 1.97 <sup>b</sup>	27.21 $\pm$ 1.83 <sup>b</sup>	36.29 $\pm$ 1.63 <sup>c</sup>					

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly ( $P<0.05$ )

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly ( $P<0.05$ )

that the mean AA content of *Fusicaulis* silage increased statistical significantly ( $P<0.05$ ) as the level of DM and molasses increased. The mean AA content in this study varied from 16.05 to 36.29%. This is higher than the 3% recommended by Kung (2001); Zimmerman (2002) and Seglar (2003). According to Wilkinson & Phillips (1979) the AA content of a well preserved silages made from perennial ryegrass and maize should be 2.6 to 3.6%. The AA content of *Fusicaulis* silage at the current study is also higher than 3.9 % for lucerne silage and 13 % for forage sorghum silage (late bloom) reported by Meeske (2000).

High levels of AA in any type of silage are indicators of less than desirable silage fermentation. The high levels of AA content at this study could be the result of organisms species commonly found in silage like *Escherchia coli* and *Erwinia herbicola*. The optimum pH for the growth of these organisms is about 7.0 and they are usually only active in the early stages of fermentation when the pH is favourable for their growth (McDonald *et al.*, 2002). A high pH of 5.3 to 7.6 was observed in the cladode silage of the present study. Therefore favourable pH exists for the growth of acetic acid

producing organisms. The production of AA was worsened by an increase of the DM and molasses level in the cladode silage. The effect of DM and molasses on the pH of cladode silage will be discussed later.

Sim *et al.* (1962) indicate that too much acetic AA resulted in a sour and unpalatable silage. This does however not apply for lactic acid. In the case of the present study a relative high pH, irrespective of the high AA content was observed. In the case of the current study the moisture content varied from 93 to 72.37 % (Table 4.1) after ensiling which is also beneficial to AA production. McCullough *et al.* (1964) reported a negative correlation between acetic concentration and dry matter content of plant material. These findings were not supported by the results of the present study (Table 4.6). Accordingly the results of the current study was in contrast with the results of Snyman *et al.* (1990). Snyman *et al.* (1990) found in general that maize silage ensiled at a low moisture content ( $54.5 \pm 3.2\%$ ) exhibited depressed fermentation characteristics when compared to material ensiled at the recommended moisture content ( $66 \pm 5.2\%$ ). When silage ensiled at a high moisture content ( $76.3 \pm 1.8\%$ ) was compared to silage ensiled at the recommended stage, fermentation activity increased. This was characterized with a significant ( $P < 0.01$ ) increase in total fatty acids and AA. The opposite results of the present study are difficult to explain. The high moisture content in the cladode silage in general could be probably played a role. It is however clear that the cladode silage contained an exceptionally high AA content. According to McDonald *et al.* (2002) well preserved grass and maize silage contain 2.4 to 3.6 % AA. This is much lower than the 13.1% to 36.3 % recorded in the present study.

Acetic acid is often produced if lactic acid production is not rapid enough to inhibit AA production by bacteria. AA is one of the parameters responsible in the aerobic stability in silages by inhibiting the growth of moulds and yeasts (Ashbell & Lisker, 1988; McDonald *et al.*, 1996). However, higher concentrations of AA may restrict palatability of silages (Muck, 1996) and depress dry matter intake in cattle (Kung, 2001). According to Heinrich (1999) higher AA production was found to be associated with lower dry matter silage, as might be the case in this study.

#### 4.4.3.2. Propionic acid (PA)

The PA content of *Fusicaulis* silage at different levels of DM and molasses inclusion is presented in Table 4.7. The results showed that no significant (P=0.23) DM x molasses interaction occurred.

**Table 4.7 - The propionic acid ( PA ) content (dry matter basis) of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means ± se)**

Molasses (%)	Propionic acid (%)				Mean	DM (p)	Mol (p)	Interaction (p)	CV (%)
	DM ( % )								
	10	20	30	40					
0	23.51 ± 7.44	32.71 ± 3.79	17.41 ± 2.37	14.23 ± 1.79	21.96 ± 2.54	0.001	0.4	0.23	40.14
8	29.03 ± 5.23	27.81 ± 2.1	20.84 ± 2.83	14.78 ± 1.31	23.11 ± 1.92				
16	35.48 ± 3.35	29.1 ± 5.63	15.64 ± 1.74	13.77 ± 1.72	23.49 ± 2.5				
24	41.58 ± 7.3	33.85 ± 2.86	15.56 ± 2.7	15.1 ± 2.13	26.52 ± 3.12				
<b>Mean</b>	32.39 ± 3.2 <sup>a</sup>	30.86 ± 1.86 <sup>a</sup>	17.36 ± 1.23 <sup>b</sup>	14.46 ± 0.83 <sup>b</sup>					

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

A higher DM in *Fusicaulis* silage resulted in a lower (P=0.001) PA content. This lower fermentation with a reduced moisture content was also observed by Van der Merwe *et al.* (1998) with lucerne silage. The PA content found in the current study varied from 14.46 to 32.39%. This was higher than the 1.4 % PA content reported by Meeske (2002) for maize silage and less than 1% DM recommended by Zimmerman (2002) & Seglar (2003). It is clear that the PA concentration in *Fusicaulis* silage was extremely high. In agreement with AA this was an indication of high fermentation activity. This high PA content of *Fusicaulis* silage could be attributed to its low DM content and or the wetness (<25 % DM) of the silage (Zimmerman, 2002).

From the Table 4.7 it further seems that molasses level in cladodes silage had no significant (P=0.4) influence on the PA concentration.

#### 4.4.3.3. Butyric acid (BA)

The influence of DM content and molasses inclusion on the butyric acid (BA) content of *Fusicaulis* silage is presented in Table 4.8. The results indicated that no significant ( $P=0.51$ ) DM x molasses interaction occurred. It is clear from Table 4.8 that a higher DM in *Fusicaulis* silage resulted in a lower ( $P<0.05$ ) BA content. No significant ( $P>0.05$ ) influence of molasses on BA in silage occurred. Kung (2001) indicated that a lower moisture content in lucerne silage, in general inhibited biological changes. The beneficial effect could be attributed to the lower moisture content which resulted in a higher concentration nutrients and thus osmotic pressure in the solution. Latter inhibit the clostridia organisms which are responsible for many of the degradation changes in silage. McDonald *et al.* (2002) indicated that clostridia are sensitive to water availability and require very wet conditions for active growth. In very wet crops with a DM of about 15 %, even the achievement of a pH value as low as 4 may not inhibit their activity. Growth of clostridia is severely restricted if the dry matter of the ensiled material is above 30% but complete inhibition may require considerably higher figures, perhaps as much as 40%. The highest DM observed in the present study after fermentation (Table 4.1) was 27.6 %. It is clear that the moisture content of the silages in the present study was in general favourable for clostridia activities.

**Table 4.8 - The butyric acid content (dry matter basis) of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Butyric acid (%)									
Molasses (%)	DM ( % )				Mean	DM (p)	Mol (p)	Interaction (p)	CV (%)
	10	20	30	40					
0	4.77 $\pm$ 1.19	6.08 $\pm$ 0.92	3.67 $\pm$ 0.43 <sup>1</sup>	3.54 $\pm$ 0.18	4.49 $\pm$ 0.43	0.001	0.08	0.051	33.07
8	5.83 $\pm$ 0.58	5.24 $\pm$ 0.61	4.21 $\pm$ 0.36	3.31 $\pm$ 0.13	4.65 $\pm$ 0.29				
16	6.47 $\pm$ 0.79	3.36 $\pm$ 0.85	3.14 $\pm$ 0.61	3.27 $\pm$ 0.27	4.06 $\pm$ 0.43				
24	7.57 $\pm$ 0.81	6.02 $\pm$ 0.41	3.69 $\pm$ 0.43	3.51 $\pm$ 0.2	5.19 $\pm$ 0.43				
<b>Mean</b>	6.16 $\pm$ 0.46 <sup>a</sup>	5.17 $\pm$ 0.41 <sup>b</sup>	3.65 $\pm$ 0.23 <sup>c</sup>	3.41 $\pm$ 0.09 <sup>c</sup>					

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly ( $P<0.05$ )

In accordance with the results of the current study, Seglar (2003) reported lower PA and BA acid in low moisture lucerne silage. These researchers observed also the same results for AA. As already discussed the opposite results were found for AA in the present study.

The BA content in the present study varied from 3.41 to 6.16 %. This was higher than the  $\pm 0.33$  % reported by Çürek & Özen (2001) for cactus silage. The mean BA content in this study were also higher than 0.28 % for lucerne silage and 2 % for forage sorghum silage (soft dough) reported by Meeske (2000). McDonald *et al.* (2002) reported butyric acid values as low as 0.14 % and 0.06 % in well preserved unwilted and wilted grass silage respectively. In maize silage butyric acid was absent. According to Zimmerman (2002) high butyric acid silage is associated with decreased dry matter intake and can be related to increased ketosis since butyric acid is a precursor of one of the ketone bodies, beta-hydroxybutyrate.

#### **4.4.4. Lactic acid (LA)**

Lactic acid is the most desirable of the fermentation acids and is the prime preservative in silage. It is mainly produced by the bacterial catabolism of WSC and organic acids (Whittenbury *et al.*, 1967). Lactic acid bacteria have a high acid tolerance and will grow at a pH range of 4.0 to 6.8. Lactobacilli grow best in slightly acidic media with an initial pH of 6.4 to 4.5 but some species will decrease the pH to 3.5 (De Brouwer *et al.* , 1991).

Lactic acid bacteria are referred to as a group of bacteria from several genera which are noted for their ability to produce lactic acid. Lactic acid bacteria (LAB) seem to coexist with plants but their role on the plant surface is still unknown. They may protect plants from pathogenic micro-organisms as LAB is found in high numbers on damaged plant parts (McDonald *et al.*, 1991).

The LA content of *Fusicaulis* silage at different levels of DM and molasses inclusion is presented in Table 4.9. A significant ( $P=0.0001$ ) DM x molasses interaction occurred which indicate that the effect of DM in a specific molasses level and or effect of molasses in a specific DM level differ.

**Table 4.9 - The lactic Acid content (dry matter basis) of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Molasses (%)	Lactic acid (%)				DM (p)	Mol (p)	Interaction (p)	CV (%)
	DM (%)							
	10	20	30	40				
0	5.4 $\pm$ 0.92 <sup>a1</sup>	6.6 $\pm$ 1.75 <sup>b1</sup>	6.93 $\pm$ 0.22 <sup>b1</sup>	7.4 $\pm$ 0.18 <sup>b1</sup>	0.0001	0.0001	0.0001	10.06
8	5.82 $\pm$ 0.74 <sup>a2</sup>	7.05 $\pm$ 0.4 <sup>b12</sup>	7.18 $\pm$ 0.29 <sup>b12</sup>	7.67 $\pm$ 0.18 <sup>b1</sup>				
16	7.36 $\pm$ 0.11 <sup>a3</sup>	8.02 $\pm$ 0.32 <sup>b2</sup>	8.36 $\pm$ 0.4 <sup>b2</sup>	9.54 $\pm$ 0.69 <sup>c2</sup>				
24	10.1 $\pm$ 0.6 <sup>a4</sup>	10.1 $\pm$ 0.31 <sup>a3</sup>	10.3 $\pm$ 0.13 <sup>a3</sup>	13.69 $\pm$ 0.5 <sup>b3</sup>				

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

It seems from Table 4.9 that a higher DM content and molasses level in *Fusicaulis* cladode silage resulted in a higher (P<0.05) LA content. The LA content of *Fusicaulis* silage in this study varied from 5.4 to 13.69 %. This was higher than the 2.59 and 3.2 % found respectively for young and old cactus silages as reported by Çüreğ & Özen (2001). The level of LA found in this study compares well with that of tropical grasses, lucerne and maize silage (10, 7.3 & 6.9 % respectively) reported by Meeske (2000). According to McDonald *et al.* (2002) well preserved unwilted and wilted grass silage contained respectively 10.2 and 5.9 % LA compared to the 5.3 % of maize silage. The minimum LA values observed for the *Fusicaulis* silage in this study satisfied the mentioned guidelines for wilted grass silage and maize silage.

#### 4.4.5. Water soluble carbohydrates (WSC)

Micro-organisms use water soluble carbohydrates as the main energy source for growth. Water soluble carbohydrates (mostly sugars) are oxidized during plant respiration. These sugars constitute the primary carbohydrates that are fermented to lactic and acetic acid by bacteria to produce a low pH and stable silage. In general, forages with less than 8 % water soluble carbohydrates in the dry matter may not reach a pH low enough to produce stable, high moisture silage. Corn, sorghum and annual grasses usually have sugar concentrations above 8% dry matter and resulted in good, stable silage. On the other hand for soybeans and other legumes have low sugar concentrations and they also have considerable buffering effect, resulting a pH decline in the 4.5 to 5.5 pH range. These

forages often do not produce stable silage, especially when forage dry matter is less than 25 % (Kunkle *et al.*, 2006).

**Table 4.10 - The water soluble carbohydrates content (dry matter basis) of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Molasses (%)	Water soluble carbohydrates (%)				DM (p)	Mol (p)	Interaction (p)	CV (%)
	DM (%)							
	<u>10</u>	<u>20</u>	<u>30</u>	<u>40</u>				
0	0.55 $\pm$ 0.02 <sup>a1</sup>	1.85 $\pm$ 0.04 <sup>b1</sup>	0.85 $\pm$ 0.02 <sup>c1</sup>	0.11 $\pm$ 0.01 <sup>d1</sup>	0.0001	0.0001	0.0001	10.3
8	1.05 $\pm$ 0.02 <sup>a2</sup>	0.62 $\pm$ 0.01 <sup>b2</sup>	1.32 $\pm$ 0.01 <sup>c2</sup>	1.04 $\pm$ 0.09 <sup>a2</sup>				
16	0.96 $\pm$ 0.01 <sup>a2</sup>	0.67 $\pm$ 0.03 <sup>b2</sup>	0.35 $\pm$ 0.02 <sup>c3</sup>	0.89 $\pm$ 0.02 <sup>a3</sup>				
24	1.29 $\pm$ 0.06 <sup>a3</sup>	0.96 $\pm$ 0.07 <sup>b3</sup>	1.55 $\pm$ 0.07 <sup>c4</sup>	1.45 $\pm$ 0.04 <sup>a4</sup>				

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

The water soluble carbohydrates (WSC) content of *Fusicaulis* silage at different levels of DM and molasses inclusion is presented in Table 4.10. A significant (P=0.0001) DM x molasses interaction occurred. The WSC in the present study varied from 0.35 to 1.85 %. These values compared well with the 1.0 and 1.6 % WSC indicated by McDonald *et al.* (2002) for unwilted grass silage and maize silage respectively. McDonald *et al.* (2002) mentioned that very little WSC remain after fermentation, usually less than 20g/kgDM.

#### 4.4.6. pH

This is the measure of the level of acidity within silage. It also gives an indication of the level of preservation within silage. Most silage have a pH between 3.8 – 4.2 and silages with a pH less than 3.6 are considered to be very acidic, while silages that have a pH greater than 4.5 may be poorly preserved. However some well preserved wilted silages may have a high pH (Cushnahan, 2006). McDonald *et al.* (2002) indicated that in such wilted silages, clostridial and enterobacterial activities are normally minimal although some growth of lactic acid bacteria occurs. It seems from Table 4.11 that a higher DM content and molasses level in *Fusicaulis* cladode silage resulted in a higher (P<0.05) pH ranging from 5.27 to 7.62. A higher pH in wilted (4.2) compared to unwilted (3.9) grass



silage was also illustrated by McDonald *et al.* (2002). This high pH in the present study prevailed in spite of a high AA and PA content as well as acceptable lactic acid content in the cladode silage. This is probably an indication of higher buffering properties of the original cladode material. According to McDonald *et al.* (2002) high pH values (5.0 to 7.0) is an indication of badly preserved silage. The main fermentation acid present is either acetic or butyric. In the present study unacceptable high levels of AA, PA and BA was detected in the cladode silage, irrespective of DM and molasses level. McDonald *et al.* (2002) mentioned that clostridia grow best at pH 7.0 – 7.4.

**Table 4.11 - The pH values of *Fusicaulis* silage at different levels of DM and molasses (means ± se)**

Molasses (%)	pH				DM (p)	Mol (p)	Interaction (p)	CV (%)
	DM (%)							
	10	20	30	40				
0	5.27 ± 0.1 <sup>a 1</sup>	5.67 ± 0.1 <sup>ab 1</sup>	6.03 ± 0.16 <sup>bc 1</sup>	6.49 ± 0.3 <sup>c 1</sup>	0.0001	0.0001	0.0001	4.4
8	5.31 ± 0.02 <sup>a 1</sup>	5.83 ± 0.02 <sup>b 1</sup>	6.12 ± 0.01 <sup>c 1,2</sup>	7.2 ± 0.02 <sup>d 2</sup>				
16	5.5 ± 0.05 <sup>a 2</sup>	5.92 ± 0.12 <sup>a 1</sup>	6.39 ± 0.08 <sup>b 2,3</sup>	7.27 ± 0.09 <sup>c 2,3</sup>				
24	5.67 ± 0.06 <sup>a 2</sup>	6.25 ± 0.09 <sup>b 2</sup>	6.45 ± 0.06 <sup>c 3</sup>	7.62 ± 0.03 <sup>d 3</sup>				

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

#### 4.4.7. *In vitro*-dry matter digestibility (IVDMD)

The *in vitro* dry matter digestibility (IVDMD) content of *Fusicaulis* silage at different levels of DM and molasses inclusion is presented in Table 4.12. The IVDMD of *Fusicaulis* silage in this study range from 58.52 % to 77.02 % at different DM and molasses levels. It seems that IVDMD in some cases increased (P<0.05) as the level of DM increased.

**Table 4.12 - The *In vitro* dry matter digestibility of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

<i>In vitro</i> Dry matter digestibility (%)								
Molasses (%)	DM (%)				DM (p)	Mol (p)	Interaction (p)	CV (%)
	10	20	30	40				
0	58.52 $\pm$ 1.4 <sup>a 1</sup>	75.56 $\pm$ 0.9 <sup>b 1</sup>	74.72 $\pm$ 1.4 <sup>b 1</sup>	73.62 $\pm$ 1.24 <sup>b 1</sup>	0.0001	0.0013	0.0001	4.4
8	74.94 $\pm$ 2.84 <sup>a 2</sup>	69.21 $\pm$ 0.65 <sup>b 2,4</sup>	76.91 $\pm$ 0.9 <sup>a 2</sup>	76.72 $\pm$ 0.9 <sup>a 2</sup>				
16	66.36 $\pm$ 0.9 <sup>a 3</sup>	71.94 $\pm$ 0.4 <sup>b 3</sup>	73.5 $\pm$ 0.7 <sup>b 1</sup>	77.02 $\pm$ 0.9 <sup>d 2,3</sup>				
24	69.89 $\pm$ 2.52 <sup>a 3</sup>	70.5 $\pm$ 0.6 <sup>a 4</sup>	74.52 $\pm$ 1.34 <sup>b 1</sup>	75.21 $\pm$ 0.8 <sup>b 1,2</sup>				

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

Although statistical significant (P=0.0013) differences occurred, no clear trend of *IVDMD* at different molasses levels could be detected. These results indicate however that *Fusicaulis* silage was highly digestible and support the values reported by Tegegne (2001). The high digestibility could be attributed, in part, to the translocation of soluble carbohydrates (Norton, 1982). The high *IVDMD* in the present study could also be related to the high cell contents, which are roughly represented by nitrogen-free extract (NFE) contents and low CF contents (Van Soest, 1982). These results were relatively lower than 77.88 % for young *Opuntia* cladodes and 82.92 % for *ficus-indica* fruits reported by Tegegne (2001) but within the 74.11; 75.12 & 77.37% range reported by Santos *et al.* (1990b), as cited by Tegegne (2001) for *Rodonda*, *Gigante* & *Miúda* cultivars respectively. Shoop *et al.* (1977) reported a non-significant difference (P>0.05) between *Opuntia* (63.8%) and alfalfa hay (63.7%) in terms of *IVDMD*.

#### 4.4.8. Gross energy (GE)

McDonald *et al.* (2002) stated that animal obtains energy from its food. The chemical energy present in a food is measured by converting it into heat energy and determining the heat produced. Gross energy is the quantity of heat resulting from the complete oxidation of unit weight of a food. McDonald *et al.* (2002) also indicated that all carbohydrates have similar ratios and about the same gross energy content (about 17.5 MJ/kg DM). Only foods rich in fat have high values, and only those rich in ash, which has no caloric value, are much lower than average. Most common foods contain

about 18.5 MJ/kg DM. Of the gross energy of foods, not all is available and useful to the animal. Some energy is lost from the animal in the form of the solid, liquid and gaseous excretions; another fraction is lost as heat (McDonald *et al.*, 2002).

The influence of DM content and molasses inclusion on the gross energy (GE) content of *Fusicaulis* silage is presented in Table 4.13.

**Table 4.13 - The Gross energy content (dry matter basis) of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Molasses (%)	Gross energy (MJ/kg)				DM (p)	Mol (p)	Interaction (p)	CV (%)
	10	20	30	40				
0	13.76 $\pm$ 0.24 <sup>a1</sup>	11.07 $\pm$ 0.08 <sup>b1</sup>	10.78 $\pm$ 0.05 <sup>b1</sup>	9.69 $\pm$ 0.3 <sup>c1</sup>	0.0001	0.22	0.0001	3.3
8	12.97 $\pm$ 0.11 <sup>a2</sup>	11.53 $\pm$ 0.08 <sup>b2</sup>	11.28 $\pm$ 0.08 <sup>b2</sup>	9.54 $\pm$ 0.19 <sup>c1</sup>				
16	12.61 $\pm$ 0.07 <sup>a2</sup>	12.2 $\pm$ 0.13 <sup>b3</sup>	11.49 $\pm$ 0.08 <sup>b3</sup>	9.51 $\pm$ 0.07 <sup>c1</sup>				
24	13.03 $\pm$ 0.21 <sup>a2</sup>	11.71 $\pm$ 0.02 <sup>b2</sup>	10.81 $\pm$ 0.11 <sup>b2</sup>	9.79 $\pm$ 0.16 <sup>c1</sup>				

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

It seems that a higher DM content in *Fusicaulis* cladode silage resulted in a lower (P<0.05) GE content. The GE content in the present study range from 9.51 to 13.76 MJ/kg which was similar to the range of GE content of most cacti (10.47 to 16.75 MJ/kg) reported by Ben Thlija (1987). The lower GE levels of *Fusicaulis* silage could be attributed to the high ash contents of the *Fusicaulis* cladodes used in this study.

#### 4.5. Conclusions

A higher DM content in *Fusicaulis* silage had influenced PA, BA and LA beneficially namely lower PA and BA accompanied with a higher LA. Accordingly LA production was increased by adding molasses to the ensiled cladodes. On the other hand a higher DM and molasses content in cladode silage was related to a higher AA content and pH value. In fact pH range from 5.27 and 7.62. This high pH occurred in spite of a high AA and PA concentration as well as acceptable LA content in the cladode silage. It is probably an indication of high buffering properties of cladode material.

Accordingly the BA content of the cladode silage was high irrespective of the positive effect of a higher DM content.

Apart from the high pH, the relative high moisture content of the cladode silage in this study could contribute to the presence of BA. Therefore the effect of a higher DM content in cladode silage on BA production warrants further research. The high moisture, AA, PA and BA content of cladode silage could have a detrimental effect on intake and animal performance.

## CHAPTER 5

### THE DIGESTIBILITY OF *OPUNTIA FICUS-INDICA* var. *FUSICAULIS* CLADODE SILAGE

#### 5.1. Introduction

Fodder conservation is promoted with the main objective of ensuring feed availability during periods of feed limitation (Mohd Najib *et al.*, 1993). It is becoming increasingly clear that the rising population has put increase pressure on agricultural land use in developing countries. There is increasing illicit use of gazetted grazing reserves for intensive crop production. This has resulted in reduced availability of free feed resources from common grazing lands. Hence, forage conservation is needed during periods of high forage productivity.

Spineless cactus pears are valued by many farmers because of their drought resistance, high biomass yield, palatability and adaptability to a range of soils and climatic regions (Zeeman & Terblanche, 1979; Ben Salem *et al.*, 1996; Batista *et al.*, 2003). Jacobs (1977) indicated that the voluntary dry mater (DM) intake by sheep of fresh spineless cactus pears is less than their maintenance requirements and the animals will loose body mass. The voluntary intake of dried and ground spineless cactus cladodes, with a much lower water content than other physical forms of spineless cactus pears, was markedly higher and consequently the loss in body mass was also much less (Jacobs, 1977).

Kunkle & Chambliss (2002) indicated that silage can be a convenient and economical feed for the cattle industry. Fresh forage crops such as maize, grasses, legumes, wheat and lucerne can be preserved by ensiling. In many countries ensiled forages are highly valued as animal feed. Even in countries with generally good weather conditions for hay making such as France and Italy approximately 50 % of the forages are ensiled (Wilinson *et al.*, 1996).

In Chapter 4 it has been stated that fresh cladodes from the spineless cactus fruit industry in south Africa is available as a feed source for ruminants. The ensiling of cladodes is an alternative manner

to preserve and store *Opuntia* cladodes as livestock feed. The influence of dry matter and molasses levels in cladode silage on the fermentation characteristics was investigated in Chapter 4. Accordingly in the present study the effects of dry matter and molasses content of ensiled cladodes on dry matter intake and digestibility by sheep was investigated.

## 5.2. Materials and Methods

### 5.2.1 Silage

*Fasicaulis* cladodes (one year-old) were harvested in March 2005 at Grootfontein experimental farm, Eastern Cape Province, South Africa. These cladodes were cut into 20 mm square pieces using a sharp knife. The same procedure as in Chapter 4 was followed. *Fusicaulis* pieces were sun-dried to obtain two levels of dry matter (DM) namely 30 and 40 percent. Two levels of molasses powder (Kalori 3000) namely 0 and 24 percent on a dry matter basis were implemented. The 24 % molasses was added and thoroughly mixed with the plant material in each dry mater level. Each mixture was put in a 200 litre plastic bag in metal drums, tightly packed and air tightly sealed (Figure, 5.1). The material was ensiled for a period of three months before opened and fed to sheep.



**Figure 5.1 – Metal drums with ensiled cladodes**

### 5.2.2 Animals

Twenty-four young Merino wethers were randomly divided into 4 groups of 6 each. The animals were weighed after a 12 hour fasting period and put in individual metabolism crates (Figure 5.2). The food was daily given at *ad libitum* at 8h00 to each sheep. Refusals and feaces were collected daily at 8h00. The refusals were weighed again to determine the amount of feed consumed by sheep per day and the feaces was also weighed and dried for analysis. The experimental period consist of a 7 day adaptation period and 18 day intake study. A collection period during the last 10 days of the intake study was implemented. The sheep were weighed again after a 12 hour fasting period at the end of the experimental period.



Figure 5.2 - Sheep metabolism crates

### **5.3. Sampling procedure**

An aliquot and representative sample in each silo were taken daily at feeding for chemical analysis.

#### **5.3.1. Analysis**

Same procedures for analysis of dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) & ether extract (EE) as described in Chapter 3 were used. The feed intake, digestible energy (DE) and live-weight gain were determined by calculation. The metabolizable energy (ME) was determined by multiplying digestible energy (DE) with 0.8 (McDonald, 1981).

#### **5.3.2. Statistical analysis**

Data was statistically analyzed as a 2x2 factorial fully randomized block design (effect of 2 DM levels and 2 molasses levels) with 6 replicates. Data were subjected to PROC ANOVA using the General Linear Model (GLM) procedure of SAS Institute (1996).

## **5.4. Results and Discussion**

### **5.4.1. Digestibility study**

#### **5.4.1.1. Chemical composition**

The chemical composition of the experimental *Fusicaulis* silages is shown in Table 5.1. It seems that the actual DM values differ from the initial target values. In fact there was only a  $\pm 1.8$  % unit increase in DM levels. This small difference could hamper an investigation on the effect of DM content of cladode silage on dry matter intake and digestibility by sheep. The DM values were however higher than those reported in Chapter 4. Accordingly higher values for fibre and CP was observed in the present study. Factors like sampling, rain and temperature could probably contribute to these differences in chemical composition.



**Table 5.1 - Chemical composition of experimental *Fusicaulis* silages on a dry matter (DM) basis**

Nutrients (%)	Molasses level (%)	DM level	
		30	40
Dry matter (DM)	0	34.74	36.63
	24	36.31	38.13
Organic matter (OM)	0	32.19	33.41
	24	33.65	34.59
Acid detergent fibre (ADF)	0	25.25	22.83
	24	23.7	21.95
Neutral detergent fibre (NDF)	0	23.05	22.27
	24	22.1	22.19
Crude protein (CP)	0	15.74	12.97
	24	14.36	15.34
Ether extract (EE)	0	2.18	3.36
	24	2.93	3.17

#### **5.4.1.2. Dry matter intake (DMI)**

The feed intake of sheep in different treatments is set out in Table 5.2. It is clear that significant ( $P < 0.05$ ) differences in dry matter intake occurred of sheep consuming the different silages. This could influence the digestibility results. McDonald *et al.* (2002) stated that an increase in the quantity of food eaten by an animal generally causes a faster rate of passage of digesta. The food is then exposed to the action of digestive enzymes for a shorter period, and there may be a reduction in its digestibility.

From Table 5.2 it seems that the statistical higher DMI of sheep consuming cladode silage with a higher DM and molasses level, could reduce digestibility coefficients.

**Table 5.2 - The average dry matter intake (DMI) of *Fusicaulis* silage by sheep during the digestibility study (means  $\pm$  se)**

DMI (kg/sheep/day)							
Molasses (%)	DM (%)		Mean	DM (p)	Molasses (p)	Interaction (p)	CV (%)
	35.5	37.4					
0	0.56 $\pm$ 0.06	0.69 $\pm$ 0.08	0.63 $\pm$ 0.07 <sup>1</sup>	0.03	0.02	0.24	13.31
24	0.71 $\pm$ 0.07	0.74 $\pm$ 0.08	0.73 $\pm$ 0.08 <sup>2</sup>				
<b>Mean</b>	0.64 $\pm$ 0.07 <sup>a</sup>	0.72 $\pm$ 0.08 <sup>b</sup>					

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

#### 5.4.1.3. Digestibility coefficients

##### 5.4.1.3.(a). Dry matter (DM)

**Table 5.3 - The apparent dry matter (DM) digestibility of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

DM (%)							
Molasses (%)	DM (%)		Mean	DM (p)	Molasses (p)	Interaction (p)	CV (%)
	35.5	37.4					
0	27.98 $\pm$ 3.95	36.28 $\pm$ 4.53	32.13 $\pm$ 2.95	0.597	0.33	0.103	15.17
24	28.11 $\pm$ 3.13	39.12 $\pm$ 3.93	35.03 $\pm$ 2.83				
<b>Mean</b>	28.05 $\pm$ 2.99	37.71 $\pm$ 2.89					

The influence of DM and molasses level in *Fusicaulis* silage on the apparent digestibility of DM is shown in Table 5.3. It is clear that no significant differences occurred in the apparent digestibility of DM. The digestibility of DM only tended to increase or decrease with a higher level of DM and

molasses respectively in the silage. It should be kept in mind that the higher DMI of sheep consuming cladode silage with a higher DM and molasses level could reduce DM digestibility. According to Castra *et al.* (1997) additives including molasses significantly increase dry matter of prickly pear silage and stimulate the rumen bacteria to increase the digestibility of dry matter. This was not supported by the results of the present study.

Ben Thlija (1987) reported higher DM digestibility values for *Opuntia cladodes* (60 to 65%). High digestibility means a faster passage of the material through the digestive tract. This also means that cactus dry matter remains in the gastrointestinal tract only for a short period of time, leaving more volume available for further intake. These findings of Ben Thlija (1987) were supported by those of Ben Salem *et al.* (1996).

#### 5.4.1.3.(b). Organic matter (OM)

From the results in Table 5.4 it is evident that the apparent organic matter (OM) digestibility of the cladode silage was not influenced ( $P>0.05$ ) by either DM and or molasses levels. The mean OM digestibility content obtained in this study was ranging from 61 to 64 %. These results were within the same range (60 to 70 %) that have been reported by Nefzaoui & Ben Salem (2002) for *Opuntia cladodes*.

**Table 5.4 - The apparent organic matter (OM) digestibility of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Molasses (%)	DM (%)		OM (%)				
	35.5	37.4	Mean	DM (p)	Molasses (p)	Interaction (p)	CV (%)
0	59.81 $\pm$ 4.41	64.05 $\pm$ 4.5	61.93 $\pm$ 3.10	0.53	0.43	0.111	15.64
24	70.1 $\pm$ 3.02	60.49 $\pm$ 4.05	64.86 $\pm$ 2.89				
<b>Mean</b>	64.48 $\pm$ 3.1	62.27 $\pm$ 2.93					

### 5.4.1.3.(c). Acid and neutral detergent fibre (ADF & NDF)

The ADF and NDF digestibility coefficients of *Fusicaulis* silage at different DM and molasses levels are presented in Table 5.5 and 5.6 respectively.

**Table 5.5 - The apparent acid detergent fibre (ADF) digestibility of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

ADF (%)							
Molasses (%)	DM (%)		Mean	DM (p)	Molasses (p)	Interaction (p)	CV (%)
	35.5	37.4					
0	26.56 $\pm$ 2.88	25.93 $\pm$ 6.07	26.25 $\pm$ 3.2	0.62	0.08	0.74	40.06
24	20.77 $\pm$ 2.19	17.57 $\pm$ 2.11	19.02 $\pm$ 1.53				
<b>Mean</b>	23.93 $\pm$ 1.99	21.75 $\pm$ 3.31					

**Table 5.6 - The apparent neutral detergent fibre (NDF) digestibility of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

NDF (%)							
Molasses (%)	DM (%)		Mean	DM (p)	Molasses (p)	Interaction (p)	CV (%)
	35.5	37.4					
0	28.57 $\pm$ 2.99	24.29 $\pm$ 3.48	26.43 $\pm$ 2.28 <sup>1</sup>	0.35	0.008	0.68	33.92
24	18.07 $\pm$ 3.72	16.42 $\pm$ 2.23	17.17 $\pm$ 1.98 <sup>2</sup>				
<b>Mean</b>	23.79 $\pm$ 2.77	20.36 $\pm$ 2.30					

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

The results showed that the apparent ADF and NDF digestibility of *Fusicaulis* silage did not significantly differ (P>0.05) between 35.5 and 37.4 % DM. The inclusion of molasses however resulted in a reduction of the ADF (P=0.08) and NDF (P=0.008) digestibilities in the *Fusicaulis* silage. McDonald *et al.* (2002) indicated that rapid fermentation of starch to volatile fatty acids

depresses the rumen pH. The low pH inhibit cellulolytic microorganisms and fibre digestibility is depressed. In this regard Nefzaoui & Ben Salem (1996a) indicated that the effective degradability of DM and NDF in the diet were significantly decreased by spineless supply. This indicated an impairment of cellulolytic activity in the rumen. Increasing cactus level in the diet decreases fibre digestibility, because of the depressing effect of the large amounts of soluble carbohydrates in cactus pads on rumen cellulolytic bacteria. The molasses used in this study seems to have the same effect.

#### 5.4.1.3.(d). Crude protein (CP)

**Table 5.7 - The apparent crude protein (CP) digestibility of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

Molasses (%)	DM (%)		CP (%)		Interaction (p)	CV (%)
	35.5	37.4	DM (p)	Molasses (p)		
0	42.89 $\pm$ 4.47	39.1 $\pm$ 3.15	0.103	0.93	0.016	23.68
24	49.52 $\pm$ 4.68	31.73 $\pm$ 3.58				

The results in Table 5.7 clearly show that the apparent crude protein (CP) digestibility in silage was not influenced by the different DM and molasses levels. The digestibility coefficient of CP in *Fusicaulis* silage range from 31.73 to 49.52 %. This was lower than the range of 35 to 70 % found by Nefzaoui & Ben Salem (2002) for CP digestibility in *Opuntia cladodes*. On the other hand Çürek & Özen (2001) reported similar values (33.21 to 44%) than those found in the current study.

#### 5.4.1.3.(e). Ether extract (EE)

The apparent EE digestibility of *Fusicaulis* silage at different levels of DM and molasses is presented in Table 5.8. The results showed that the apparent digestibility of EE was reduced by a higher DM content in the *Fusicaulis* silage. This reduction is difficult to explain. The digestibility of EE did however not differ (P=0.15) between 0 and 24% molasses levels.

**Table 5.8 - The apparent ether extract (EE) digestibility of *Fusicaulis* silage at different levels of dry matter (DM) and molasses (means  $\pm$  se)**

		EE (%)					
Molasses (%)	DM (%)		Mean	DM (p)	Molasses (p)	Interaction (p)	CV (%)
	35.5	37.4					
0	58.1 $\pm$ 5.1	41.45 $\pm$ 5.1	49.77 $\pm$ 4.25 <sup>1</sup>	0.006	0.15	0.502	22.56
24	48.46 $\pm$ 4.7	37.81 $\pm$ 1.72	42.65 $\pm$ 2.75 <sup>1</sup>				
<b>Mean</b>	53.72 $\pm$ 3.66 <sup>a</sup>	39.63 $\pm$ 2.6 <sup>b</sup>					

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

#### 5.4.1.4. Metabolizable energy (ME)

Metabolizable energy (ME) is that portion of the gross energy (GE) consumed which is utilized by animal for accomplishing work, growth, fattening, fetal development, milk production, and/or heat production. It is that portion of the GE not appearing in the feces, urine, and gases of fermentation (principally CH<sub>4</sub>). It is digestible energy (DE) minus the energy of urine and methane (Cullison, 1975).

The metabolizable energy (ME) content of *Fusicaulis* silage at different levels of DM levels and molasses inclusions is set out in Table 5.9. No statistical significant (P>0.05) influence of DM and molasses levels on the ME content of cactus cladodes could be detected.

**Table 5.9 - The metabolizable energy (ME) contents of *Fusicaulis* silage at different levels of DM and molasses (means  $\pm$  se)**

		ME (MJ/kg)					
Molasses (%)	DM (%)		Mean	DM (p)	Molasses (p)	Interaction (p)	CV (%)
	35.5	37.4					
0	6.11 $\pm$ 0.77	5.89 $\pm$ 0.39	6.01 $\pm$ 0.33	0.422	0.53	0.73	18.83
24	6.59 $\pm$ 0.29	6.03 $\pm$ 0.23	6.31 $\pm$ 0.35				
<b>Mean</b>	6.35 $\pm$ 0.35	5.96 $\pm$ 0.33					

In spite of the low DMI of sheep that could result in higher digestibility values, low ME values for *Fusicaulis* silage was recorded. These low values could be attributed to the laxative effect of *Fusicaulis* silage. This effect is not a disease symptom and has no detrimental effect on animals, but it has the disadvantage because food passes through the digestive tract faster and reduce digestibility. Where access to grazing veld is not possible, a supplement of any roughage or by adding 3% feeding lime to the ration will counteract the laxative effect (De Kock, 1998). It appears that hay, as a supplement, retards this laxative effect to a certain extent. This is another reason why lucerne hay is regarded as an exceptionally suitable supplement to spineless cactus in any form (De Kock, 1980 ).

#### **5.4.1.5. Intake study**

##### **5.4.1.5.(a). Dry matter intake**

The more food that an animal can consumes each day, the greater will be the opportunity for increasing its daily production. An increase in production, which is obtained by higher food intakes, is usually associated with an increase in overall efficiency of the production process. In the alimentary tract the food is digested and the nutrients are then absorbed and metabolized. All these processes can influence food intake on a short term basis (McDonald *et al.*, 1991). McDonald *et al.* (1991) also mentioned that silages with a low pH value and rich in fermentation acids, or, alternatively badly fermented silages containing high concentration of ammonia are typical of a low intake silage. The exact explanation for these lower intake of silage diets is not known. Ensiling techniques such as wilting, use of certain additives and fine chopping are known to improve silage DM intake.

The rate of feed intake by an animal is influenced by factors like species, variety, season, cladode age, and their corresponding interactions (Ben Salem, 1996). Nefzaoui & Ben Salem (2002) stated that, generally, cacti are highly palatable.

The feed intake of *Fusicaulis* silage at different levels of DM and molasses is illustrated in Table 5.10. It is clear that the DM content of *Fusicaulis* silage had no influence ( $P=0.42$ ) on the dry matter intake (DMI) by sheep. The inclusion of molasses at ensiling however influenced DMI by sheep favourably ( $P=0.054$ ). It probably increased the palatability of the silage.

**Table 5.10 - The average dry matter intake (DMI) of *Fusicaulis* silage by sheep during the experimental period of 18 days (means  $\pm$  se)**

DMI (kg/sheep/day)							
Molasses (%)	DM ( % )		Mean	DM (p)	Molasses (p)	Interaction (p)	CV (%)
	35.5	37.4					
0	0.73 $\pm$ 0.03	0.76 $\pm$ 0.01	0.74 $\pm$ 0.01 <sup>1</sup>	0.42	0.054	0.85	12.74
24	0.81 $\pm$ 0.03	0.85 $\pm$ 0.01	0.83 $\pm$ 0.01 <sup>1</sup>				
<b>Mean</b>	0.77 $\pm$ 0.02 <sup>a</sup>	0.81 $\pm$ 0.01 <sup>a</sup>					

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)

<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

Preston & Leng (1987) indicated that supplementation of poor quality roughages with molasses increased their palatability. The mean feed intake of *Fusicaulis* silage by sheep range from 0.74 to 0.83 kg DM/sheep/day. This was lower than the 1.1kg DM/sheep/day for sheep fed *Opuntia ficus-indica* cladodes (De Kock, 1998). The daily DMI of sheep in the present study were however higher than the 0.65 kg reported by Valdes & Flores (1967), as cited by Nefzaoui & Ben Salem (2002) for *Opuntia Rubasta* cladodes. This could be attributed to the factors that are already mentioned.

#### **5.4.1.5.(b). Metabolisable energy intake (MEI)**

The metabolizable energy intake of *Fusicaulis* silage at different levels of DM and molasses is presented in Table 5.11. In contrast with molasses, a higher DM level (37.4 % DM) in silage resulted in a higher MEI. According to McDonald *et al.* (2002) the daily maintenance requirement of wethers with a body mass of  $\pm$  28 kg is  $\pm$  4.2 MJ ME. From the MEI results in Table 5.11 it seems that cladode silage will more or less supply in the ME maintenance requirements of wether lambs with an average body weight of 30  $\pm$  0.05 kg used in the present study.



**Table 5.11 - Metabolizable energy intake (MEI) of sheep consuming *Fusicaulis* silage with different levels of DM and molasses (means  $\pm$  se)**

		MEI (MJ/kg)					
Molasses (%)	DM (%)		Mean	DM (p)	Molasses (p)	Interaction (p)	CV (%)
	35.5	37.4					
0	3.81 $\pm$ 0.27	4.63 $\pm$ 0.16	4.22 $\pm$ 0.22 <sup>1</sup>	0.001	0.65	0.25	9.09
24	4.08 $\pm$ 0.13	4.51 $\pm$ 0.08	4.3 $\pm$ 0.11 <sup>1</sup>				
<b>Mean</b>	3.95 $\pm$ 0.2 <sup>a</sup>	4.57 $\pm$ 0.12 <sup>b</sup>					

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)  
<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

#### 5.4.2. Live-weight

The live-weight changes of Merino wethers consuming *Fusicaulis* silage at different levels of DM and molasses is illustrated in Table 5.12. The results showed that wethers with no molasses lost more (P=0.07) weight. This weight loss could be attributed to a deficit in protein and energy intake. Rossouw (1961) reported that bovines fed exclusively *Opuntia* cladodes showed no real increase in live-weight.

**Table 5.12 - The average live-weight gain of merino wethers consuming *Fusicaulis* silage with different levels of dry matter (DM) and molasses during the experimental period of 18 days (means  $\pm$  se)**

		Live-weight gain (kg/day)					
Molasses (%)	DM (%)		Mean	DM (p)	Molasses (p)	Interaction (p)	CV (%)
	30	40					
0	-0.13 $\pm$ 0.05	-0.17 $\pm$ 0.07	-0.15 $\pm$ 0.06 <sup>1</sup>	0.84	0.07	0.612	145.29
24	-0.05 $\pm$ 0.03	-0.03 $\pm$ 0.02	-0.04 $\pm$ 0.03 <sup>1</sup>				
<b>Mean</b>	-0.09 $\pm$ 0.04 <sup>a</sup>	-0.2 $\pm$ 0.05 <sup>a</sup>					

<sup>a,b,c,d</sup> = Means in row with different alphabetic superscripts differ significantly (P<0.05)  
<sup>1,2,3,4</sup> = Means in column with different numeric superscripts differ significantly (P<0.05)

Terblanche *et al.* (1971) is of the opinion that *Opuntia* cladodes should be dried to prevent losses in live-weight. From Table 5.12 it is clear that DM level at ensiling did not influence ( $P=0.84$ ) the weight changes of the sheep. These findings supported the DMI and MEI results as already discussed. In spite of a high CV, weight losses were decreased ( $P=0.07$ ) by the inclusion of molasses at ensiling. The experimental period was however short and should the results be interpreted with caution.

### **5.5. Conclusions**

From the results of the present study it seems, that with the exception of EE, the digestibility of DM, OM, fibre and CP were not influenced by the DM content of the cladode silage. Accordingly ME content, DMI and live-weight gain of sheep were similar for cladode silage containing different levels of DM. The small differences in the DM content of the experimental cladode silages could contribute to these findings.

In contrast with DM, OM and CP digestibility, the inclusion of molasses reduced fibre digestibility. The ME content of the cladode silage was however not alter by the inclusion of molasses in the cladode silage. A favourable influence of molasses on silage DMI and weight losses were however detected.

In general it seems that the laxative effect of cladodes resulted in a higher rate of passage through the digestive tract. Accordingly the digestibility and ME content of cladode silage is relatively low. Accompanied by a low DMI, cladode silage as a sole energy source only supplied in the maintenance requirement of sheep, especially when molasses was included at ensiling of the plant material.

## Chapter 6

### General conclusions

The developing fresh fruit industry in South Africa resulted in more cladodes to become available as animal feed when the plants are pruned to stimulate fruit production. Accordingly various *Opuntia* varieties are used for fruit production. From the results of the present study it seems that the nutritional value of different cladode varieties differ.

Although a higher dry matter content was observed for *Chicco* compared to *Castello*, *Fusicaulis*, *Montery*, *Morado* and *Rubasta* cladodes varieties, the dry matter (DM) content of the different *Opuntia* varieties was generally low. This high moisture content in cactus cladodes could serve as an important water source for animals during periods of drought.

On the other hand the high moisture content of cactus cladodes hampers the practical use thereof, as an animal feed. In the first place it is not always economical and practical to transport such bulk material. Secondly wet cladodes can not be store for long periods. Thirdly the dry matter intake of high moisture plant material by animal is lower. These problems could be overcome by drying the cladodes. It is however a time consuming process if sun light is used or expensive when artificially dried. Furthermore moisture loss is hampered by the mucilage around the leaves.

From the chemical analysis it further seems that the *Morado* variety was the only one with a high enough protein content to ensure sufficient microbial growth and digestion of cladodes for maintenance purposes. According to the fibre fractions and NFC values, *Montery* and *Chicco* would result in the lowest energy intake. Furthermore it is high in ash and especially the minerals Mg, K and Ca. The high Mg content could probably be associated with the laxative effect of *Opuntia* cladodes. According to its chemical composition *Opuntia* cladodes could be classified as a high moisture, energy source with an energy level ranging between that of a roughage and concentrates, with a low CP and high Mg, K, and Ca content. The dry matter intake and digestibility of cladodes would however eventually determine its nutritional value as an animal feed.

The ensiling of cactus cladodes is an alternative method to preserve and store it as an animal feed. It seems however from the results of the present study that cactus cladode silage with less than about 30% DM will result in badly preserved silage irrespective of the inclusion level of molasses. This high moisture is favourable for AA, PA and BA production which would probably contribute to a low dry matter intake (DMI) by sheep. This was confirmed by the intake study where the intake of cladode silage with a higher DM content (37%) was relatively low. Although a higher DM content in *Fusicaulis* silage were associated with a higher LA and lower PA and BA production, the actual minimum moisture content in the fermentation study was probably still too high to prevent badly preserved silage in which both clostridia (BA) and enterobacteria (AA) have dominated the fermentation. Irrespective of the beneficial effect of molasses on LA production, badly preserved silage occurred. The production of BA was probably aggravated by an unacceptable high pH value, ranging from 5.3 to 7.6. Furthermore pH values were increased by higher DM and molasses levels. This high pH occurred in spite of a high AA and PA concentration as well as acceptable LA content in the *Fusicaulis* silage. It is probably an indication of high buffering properties of the cladode plant material.

Apart from the badly preserved cladode silage, the laxative effect of cladodes resulted in a higher rate of passage through the digestive tract. This was probably related to the relatively low observed digestibility coefficients and metabolisable energy (ME) content of cladode silages irrespective of DM and molasses inclusion level. The inclusion of 24% molasses at ensiling increased the palatability and DMI of cladode silage. It seems from the results of the present study that cladode silage as sole energy source will only supply in the maintenance requirement of sheep especially when molasses is included at ensiling of the plant material. The inclusion of dry hay at ensiling to reduce the moisture content of cladode silage, warrants further investigation.

## Abstract

A laboratory study was undertaken to investigate the nutritional value of different *Opuntia* varieties from chemical analysis. One year old cladodes from six different varieties of *Opuntia ficus-indica* namely *Castello*, *Chicco*, *Fusicaulis*, *Montery*, *Morado* and *Rubasta* were randomly harvested in five replicates. The highest ( $P<0.05$ ) average dry matter (DM) content was observed for the *Chicco* variety and was the average for all varieties generally low (9.13%). There were no significant difference ( $P>0.05$ ) in ash content. Significant ( $P<0.05$ ) differences among varieties were recorded for crude protein (CP) (3.7 to 8.1%), acid detergent fibre (ADF) (13.6 to 17.4%), neutral detergent fibre (NDF) (19.9 to 38.5%), cellulose (2.4 to 14.8%), hemicellulose (4.5 to 12.7%), lignin (2.51 to 21.5%), non fibre carbohydrates (NFC) (33.4 to 48.6%), ether extract (EE) (1.9 to 2.4%). The average mineral composition were as follows, phosphorus (P) 0.18%, potassium (K) 3.02%, calcium (Ca) 2.3%, magnesium (Mg) 3.6% and sodium (Na) 0.04%. It was concluded that in general cladodes could be classified as a high moisture energy source with an energy level between that of roughages and concentrates with a low CP and high Mg, K and Ca content.

In a second study the influence of dry matter (7.12 to 27.6 %) and molasses (0 to 24%) content on the fermentation characteristics of *Fusicaulis* cladode silage was investigated. One year old cladodes was ensiled in three litre square plastic bottles (six replicates). A higher DM content were characterized with a lower ( $P<0.05$ ) ADF, NDF, CP and EE content. The inclusion of molasses resulted in a lower ( $P<0.05$ ) ADF, NDF and EE content. An increased ( $P<0.05$ ) acetic acid (AA) content in *Fusicaulis* silage was observed as the level of DM and molasses increased. A higher silage DM content resulted in a lower ( $P<0.05$ ) propionic acid (PA) and butyric acid (BA) content. No significant ( $P>0.05$ ) influence of molasses on PA and BA occurred. Lactic acid (LA) content and pH of cladode silage was increased ( $P<0.05$ ) by higher DM and molasses levels. It was concluded that the content of cladode silage could have detrimental effect on intake and animal performance.

In a third study, the effect of DM (35.5 and 37.4%) and molasses (0 and 24%) content of ensiled cladodes on dry matter intake (DMI) and apparent digestibility by sheep was investigated. Twenty-four merino wethers were randomly divided into 4 groups of 6 each. No statistical significant

( $P > 0.05$ ) influence of DM and molasses levels in *Fusicaulis* silage on the apparent digestibility of DM and CP as well as metabolizable energy (ME) content occurred. The inclusion of molasses resulted in a reduction in the ADF ( $P = 0.08$ ) and NDF ( $P = 0.05$ ) digestibilities. Apparent EE digestibility was reduced ( $P < 0.05$ ) by a higher DM level. DM content of cladode silage had no influence ( $P = 0.42$ ) on DMI by sheep. The inclusion of molasses influenced DMI favourably ( $P = 0.54$ ). In contrast with molasses, a higher DM level (37.4%) in silage resulted in a higher ( $P < 0.05$ ) metabolizable energy intake (MEI). Cladode silage supplied more or less in the ME requirements of 30 kg wether lambs. Weight losses were decreased ( $P = 0.07$ ) by the inclusion of 24% molasses. It was concluded that the laxative effect of cladode silage resulted in a higher rate of passage through the digestive tract. Accordingly the digestibility and ME content of cladode silage is relatively low. Accompanied by a low DMI, cladode silage as a sole energy source supplied only in the maintenance requirement of sheep, especially when molasses was included at ensiling.

## Opsomming

'n Laboratoriumstudie is uitgevoer om die voedingswaarde van verskillende *Opuntia* variëteite vanaf chemiese ontledings te ondersoek. Eenjaar-oud turksvyblare vanaf ses verskillende variëteite van *Opuntia ficus-indica* naamlik *Castello*, *Chicco*, *Fucicaulis*, *Montery*, *Maroda* en *Rubasta* is ewekansig in vyf replikasies geoes. Die hoogste ( $P < 0.05$ ) gemiddelde droëmateriaalinhoud (DM) is vir die *Chicco* variëteit waargeneem en was die gemiddeld vir al die variëteite oor die algemeen laag (9.13%). Geen betekenisvolle ( $P < 0.05$ ) verskille in asinhoud het voorgekom nie. Betekenisvolle ( $P < 0.05$ ) verskille tussen variëteite is vir ruproteïen (RP) (3.7 tot 8.1%), suurbestande vessel (SBV) (13.6 tot 17.4%), neutraalbestande vessel (NBV) (19.9 tot 38.5%), sellulose (2.4 tot 14.8%), hemisellulose (4.5 tot 12.7%), lignien (2.5 tot 21.5%), nie-veselkoolhidrate (33.4 tot 48.6%), eterekstrak (EE) (1.9 tot 2.4%) waargeneem. Die gemiddelde mineraalsamestelling was as volg: fosfaat (P) 0.18%, kalium (K) 3.02%, kalsium (Ca) 2.3%, magnesium (Mg) 3.6% en natrium (Na) 0.04%. Daar is tot die slotsom gekom dat turksvyblare in die algemeen as 'n hoë energiebron met 'n energiepeil tussen die van 'n ruvoer en kragvoer, met 'n lae ruproteïen en hoë Mg, K en Ca- inhoud geklassifiseer kan word.

In 'n tweede studie is die invloed van DM-(7.12 tot 27.6%) en melasse-inhoud (0-24%) op die fermentasie-eienskappe van *Fusicaulis* turksvyblaarkuilvoer ondersoek. Eenjaar-oud turksvyblare is in drie liter vierkantige plastiese bottels (ses replikasies) ingekuul. 'n Hoër DM- inhoud is gekenmerk met 'n laer ( $P < 0.05$ ) SBV-, NBV-, RP- en EE- inhoud. Die insluiting van melasse het 'n laer ( $P < 0.05$ ) SBV-, NBV- en EE- inhoud tot gevolg gehad. 'n Hoër ( $P < 0.05$ ) asynsuurinhoud (AA) in *Fusicaulis* kuilvoer is waargeneem soos die DM en melassepeile toeneem het. 'n Hoër kuilvoer DM- inhoud het met 'n hoër ( $P < 0.05$ ) propioonsuur (PA) en battersuurinhoud gepaardgegaan. Geen betekenisvolle ( $P < 0.05$ ) invloed van melasse op PA en BA het voorgekom nie. Melksuur en pH van turksvyblaarkuilvoer het met hoër DM- en melassepeile toeneem. Daar is tot die slotsom gekom dat die hoë vog, AA-, PA- en BA- inhoud van turksvyblaarkuilvoer, inname en diereprestasies nadelig kan beïnvloed.

In 'n derde studie is die effekte van DM- (35.5 en 37.4%) en melasse- (0 en 24%) inhoud van eenjarige ingekuilde turksvyblare op die droëmateriaalinname (DMI) en skynbare verteerbaarheid deur skape ondersoek. Vier en twintig Merinohamels is ewekansig in 4 groepe van 6 elk ingedeel. Geen statisties betekenisvolle ( $P > 0.05$ ) invloed van DM- en melassepeile in *Fusicaulis* kuilvoer op die skynbare verteerbaarheid van DM en RP asook metaboliseerbare energie- (ME) inhoud het voorgekom nie. Die insluiting van melasse het SBV- ( $P = 0.08$ ) en NBV- ( $P = 0.005$ ) verteerbaarheid verlaag. Skynbare EE- verteerbaarheid is deur 'n hoër DM- inhoud verlaag ( $P < 0.05$ ). DM- inhoud van turksvyblaarkuilvoer het nie DMI van skape beïnvloed ( $P = 0.42$ ) nie. Die insluiting van melasse het DMI positief beïnvloed ( $P = 0.054$ ). In teenstelling met melasse, het 'n hoër DM- peil (37.4%) in kuilvoer met 'n hoër ( $P < 0.05$ ) ME- inname gepaardgegaan. Turksvyblaarkuilvoer het min of meer in die ME- onderhoudsbehoefte van 30kg Merinohamels voorsien. Gewigsverliese is verminder ( $P = 0.07$ ) deur die insluiting van 24% melasse. Daar is tot die slotsom gekom dat die lakseereienskappe van turksvyblaarkuilvoer die spoed van deurgang deur die spysverteringskanaal verhoog. Gevolglik is die verteerbaarheid en ME- inhoud van turksvykuilvoer relatief laag. Gepaard met 'n lae DMI, voorsien turksvyblaarkuilvoer as enigste energiebron slegs in die onderhoudsbehoefte van skape, veral waar melasse met inkuiling ingesluit is.



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